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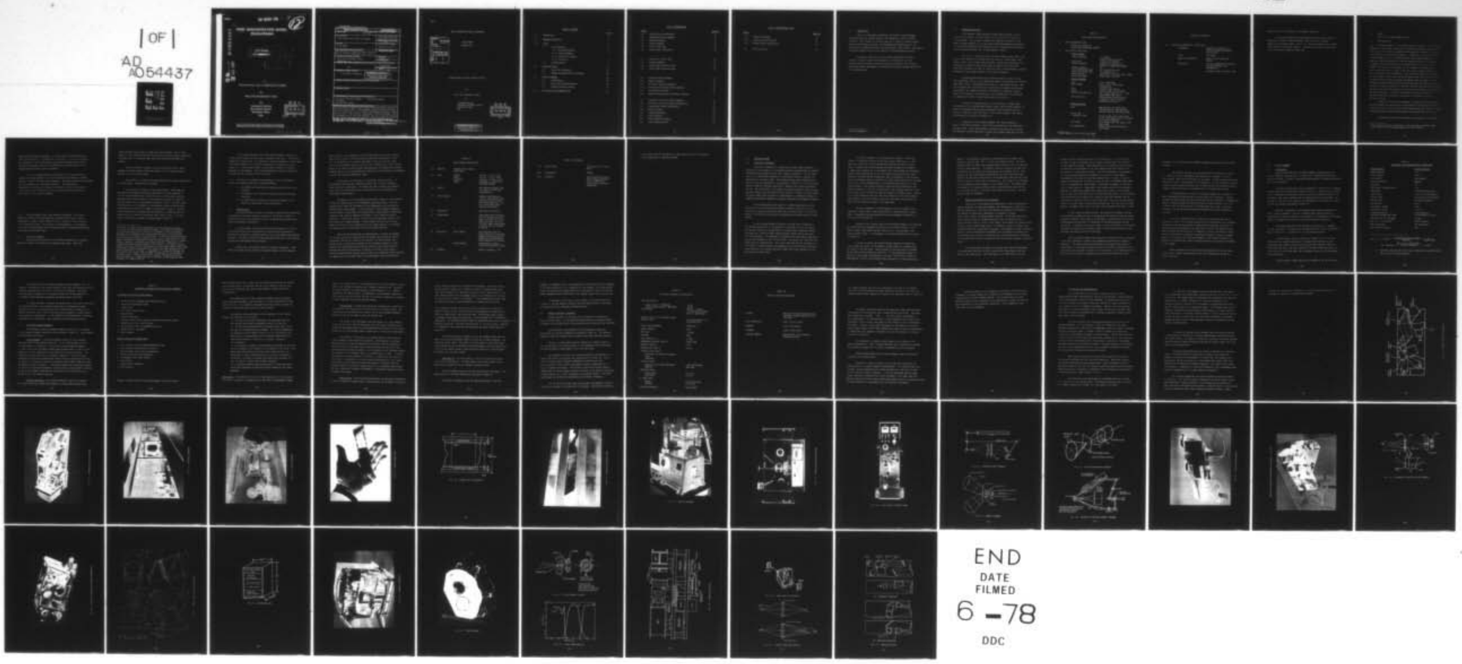

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HHSD DEMONSTRATION MODEL DEVELOPMENT

(9) Final Report Sep 76 - Dec 77

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(10) G. T. Burton
B. R. Clay

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This Final Report summarizes the status of the Holographic Horizontal Situation Display effort. This program's objective was the development and optimization of the techniques and hardware required to demonstrate a bright, high contrast, annotatable, multicolor display. Display hardware with a CRT, tape transport and source tapes were developed that demonstrate the characteristics of the focussed image holographic storage technique as applied to the annotated moving map display requirement of the HHSD application of the AIDS program.

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FINAL REPORT

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.)

1.0 INTRODUCTION

This is a Final Report summarizing the status of the Holographic Horizontal Situation Display effort at the completion of Contract N62269-76-C-0390. This contract is the most recent of a series of contracts dating back to 1969* having as an object the development and optimization of the techniques and hardware required to provide a bright, high contrast, annotatable, multicolor display for use in the cockpit of a high performance aircraft.

The specific objective of this current program was to provide hardware and source tapes that demonstrate the characteristics of the focussed image holographic storage technique when applied to the annotated moving map display requirement of the Horizontal Situation Display application of the AIDS program.

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*Listed in Appendix 1

2.0 HARDWARE DESCRIPTION

The developed concept employs focussed image holograms to store multicolor information as phase gratings on the surface of a transparent storage medium. The recording technique which employs photoresist as the basic recording material is one that allows rapid and inexpensive duplication of the stored information by a pressing process in thermal plastic materials such as polyvinylchloride, PVC; or polycarbonate, "Lexan".

For use in a cockpit horizontal situation display system, 14½" x 14½" aerial chart segments are recorded along the length of a 32mm "Lexan" tape strip as 21mm x 21mm focussed image holograms. Registration and address information is recorded on edge tracks along the length of the tape strip. This latter information is used in conjunction with a high performance transport mechanism to allow rapid retrieval of the stored information.

A display system having the configuration shown in Figure 2-1 has been implemented, Figure 2-2, as a laboratory system to demonstrate the focussed image HHSD concept. The demonstration system is a dual display system. Both the holographically stored multicolor information and dynamic CRT generated alpha-numeric and graphical annotation information are displayed through a common 5-inch diameter viewing aperture. The characteristics of the display are summarized in Table 2-1 and in more detail in Section 5.0.

To support the display system, or more correctly, to demonstrate the features of the focussed image storage concept, the recording hardware of Figure 2-3 assembled under previous programs has been refined and used to record the tapes which were the object of this current program. This system is discussed in more detail in Section 4.0.

In addition to the recording hardware, the coating hardware of Figure 2-4 has been developed to allow in-house generation of the photoresist recording tapes. Using this hardware, photoresist and antihalation coatings are applied to a mylar substrate to produce the recording tapes that are used

TABLE 2-1

HHSD SYSTEM CHARACTERISTICS

I. DATA PRESENTATION FORMS

- MULTICOLOR MOVING MAP
- DYNAMIC MAP ANNOTATION (STROKE)

II. MAP DISPLAY (MULTICOLOR)

- IMAGE FEATURES

DISPLAY APERTURE:	5" DIAMETER VIEWING SCREEN (X30 GAIN)
RESOLUTION:	8 lp/mm, 40% RESPONSE
DISPLAY CONTRAST:	ADEQUATE FOR VIEWING IN A 10,000 FT. LAMBERT ENVIRONMENT
VIEWING DISTANCE:	30"
IMAGE PRESENTATION SIZE:	4/3 ORIGINAL MAPS SIZE
VIEWING EYE RELIEF AREA:	10" DIAMETER @ 30"
COLOR FIDELITY:	EQUIVALENT TO EXISTING AERIAL CHARTS
PROJECTION SOURCE:	WHITE LIGHT, 300 WATTS

- STORAGE HOLOGRAM

SIZE:	21mm x 21mm/FRAME
AREA STORAGE:	14.5" x 14.5" AERIAL CHART SEGMENT/FRAME
TYPE:	FOCUSSED IMAGE (PHASE)
MEDIUM:	PRESSED LEXAN (POLYCARBONATE)
PACKING CONFIGURATION:	500 - 21mm FRAMES ON A 45' - 35mm UNPERFORATED TAPE STRIP*
ADDITIONAL DATA:	FRAME ADDRESS AND REGISTRATION INFORMATION (HYBRID FRESNEL - FRAUNHOFER EDGE TRACK)

- TRANSPORT SYSTEM

TYPE:	REEL-TO-REEL, TWO MOTOR DRIVE FOR RAPID ACCESS, STEPPING MOTOR CAPSTAN DRIVE FOR FINE POSITIONING
ACCESS TIME	
CONTINUITY JUMP:	600 ms TO JUMP FROM A GIVEN FRAME TO ANY OTHER FRAME WITHIN $\pm$ 30 FRAMES AND COME UP REGISTERED
LOOK AHEAD:	6 sec (WORST CASE) ANY FRAME TO ANY OTHER FRAME
X-Y TRANSLATION:	TRACKING MODE TAPE POSITIONED TO 1/500 FRAME

*System supplied with 16 active map frames

TABLE 2-1 (Continued)

III.	DYNAMIC MAP ANNOTATION - DIRECT VIEW	
	BRIGHTNESS:	ADEQUATE FOR VIEWING IN A 10,000 FT-CANDLE ENVIRONMENT OVER MAP DATA
	COLOR:	P-43 GREEN
	MEANS OF COMPOSITION:	STROKE (20,000 INCHES PER SECOND)
	RESOLUTION:	OVER MAP PRESENTATION COMPATIBLE WITH ALPHA NUMERIC DATA PRESENTATION
		CONTINUOUS TONE, SPOT SIZE, .006"

during the initial recording of a holographic tape strip.

RCA also maintains plating and pressing facilities that allow the generation of metallic pressing masters, which are used to generate duplicate Lexan display tapes, Figure 2-5. The Lexan tapes are the storage tapes used with the display hardware. Information is stored on these tapes in the configuration shown in Figure 2-6.

3.0 STATUS

What is the current hardware status?

3.1 Tape Generation

3.1.1 Recording Hardware - The recording system of Figure 2-3 is operational. There are in this system, two distinctly different holographic recording sub-systems; one for recording the address and registration information, a second for recording multicolor map information. In addition to the two optical recording systems, there is incorporated within the recording hardware, a sequencing subsystem designed to guide the operator through the multistep recording process required to record extended length tape strips. This system[1] was found to be necessary for the recording of extended length tape strips, directly as a result of the fact that an operator mistake in any one recording step could destroy a tape strip having many hours invested in its recording. Quite often the mistake would remain undetected until the recording process had been completed and duplicate tapes generated. An unmonitored recording operation previously required that the operator maintain a degree of diligence, difficult to sustain, through a long and tedious process. The sequencing system monitors both the multicolor and address and registration recording operations. It directs the operator to specific steps in the recording operation and inhibits a recording if the operator has made a procedural mistake.

Currently, the multicolor holographic recording system is producing butted holograms; hue shifts across butted joints are still present, however. The procedure used to butt the map storage holograms has been refined; it allows consistent generation of butted holograms with minimized gaps at the joint.

Problems have also been encountered in the generation of consistent

(1) The sequencing system is described in the Final Report published under Contract N62269-76-C-0134 dated November 1976 (NADC-75194-30)

address and registration holograms. As of this writing, these difficulties have not been solved. The problems are of two types. One is associated with the complexity of the hologram and the multi-step recording process used to generate the hologram, while a second problem can be traced directly to the sequencing system used to control recording.

It was not possible within the resources of the current program, to refine this recording system to the extent necessary to establish a reliable method of recording the edge track information. The tapes that have been supplied with the equipment are of limited usefulness. The difficulties encountered in recording the address data requires a review of the approach used to record this information and will most certainly require extensive modification of the recording hardware.

3.1.2 Coating Hardware (Source Tape Generation Equipment) - The coating hardware of Figure 2-4 has performed well throughout the program. While a requirement to produce a large number of tapes - production such as required for an operational system - would result in the desirability of new hardware, the current coating equipment would effectively support the HHSD program through a preproduction prototype phase.

3.1.3 Duplication Hardware

The duplication process as it is currently implemented, is a limited system not suited to the production of extended length tapes. Under this

current program, master tapes 10 frames long* were produced. Sets of these tapes, i.e., four different masters, were used in successive pressing operations to produce the 4 x 4 map array tape strips that were delivered under this program.

While the system is limited, it can be effectively used to supply hardware evaluation tapes as long as the extent of east to west butting is limited to four active map frames.

The extension to a larger east-west dimension will require modifications in several areas. Consider what is required.

The duplication process is a three-step process. Having made and developed the holographic photoresist tape strip, it is next required to coat the relief hologram with a conductive film. In the process currently employed at RCA, gold is applied to the photoresist surface to a depth of several hundred um by a vacuum deposition process - Step 1. The gold coated photoresist acts as the cathode in an electrolytic process in which nickel is deposited over the gold to a depth of several mills - Step 2. The gold faced nickel master is stripped from the photoresist, cleaned and used as a pressing master to produce the duplicate lexan copies - Step 3. The three tapes of the process are shown in the photograph of Figure 3-1.

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* Currently, in order to allow demonstration of the laboratory equipment, a 4 x 4 array of aerial charts has been recorded. Four charts are butted in the east-to-west direction in each of four sequential tape strip masters. The tapes are overlapped in the north-south direction to allow continuous coverage over a 400 nm by 300 nm ground area. In order for effective utilization of the rapid retrieval transport system, X and Y registration and frame address information is required not only for the map frames, but for 3 lead-in frames in advance of and behind the storage positions. (Examination of a recorded tape shows that there appears to be 2 lead in and 4 lead out address frames; this results from the configuration of the display hardware which reads the address information associated with a particular frame displaced in the lead out direction of one frame.) Consequently, 10 frames are required for each group of four frames to be recorded. An east-west set is recorded as one master strip. During the duplication process, the individual master tapes are pressed on a Lexan tape strip to provide a single duplicate tape containing the complete map set.

Both the gold deposition and nickel plating hardware currently in existence will support the production of extended length tapes. The pressing system will, however, have to be modified to allow the pressing of longer tapes. The pressing operation is currently performed using the hydraulic press of Figure 3-2. A roller press similar to that shown in Figure 3-3 could be modified for this purpose. (The double sided pressing system of Figure 3-4 has been used with limited success in the past.)

3.1.4 Conclusion - To support future programs, it will be necessary to modify the following areas of the recording hardware.

(1) The address and registration recording system will have to be modified.

(2) The sequencer that controls the recording operation requires refinement.

(3) If longer tapes are required, the pressing hardware of the duplication system will require modification.

3.2 Display System

The display system of Figure 2-2 has been completed and is operational. As indicated in the block diagram of Figure 2-1, the system is capable of presenting multicolor map information as well as dynamically generated alpha numeric and graphical information.

A limited number of display tapes have been assembled for use with the system providing the source material for the multicolor presentation. The system is designed to interface directly with a Kaiser Model 2001 character generator. Interfacing through the AIDS experimental data bus is also possible although level adjustments may be required.

As delivered, the equipment meets the program requirements. There are several areas, however, where the system performance could be improved.

These include (1) the replacement of the existing beam splitter with a higher quality unit, one more closely matching the specified requirements of Table 3-1; (2) the addition of a contrast enhancement filter over the face plate of the CRT as discussed further in Section 5-3;(3) modification of the transport system to (a) reduce a jitter problem associated with the stepping motor advance increment and (b) revise the address and registration sensing system to accommodate a revised and simplified addressing system.

The equipment as delivered, is a laboratory evaluation model. It was assembled using existing components derived from a series of programs dating back over several years. No attempt was made to package the hardware, other than that the head end optical configuration is that recommended for future direct view systems.

The system, as it is assembled, allows direct viewing of the annotation CRT and the viewing screen of the holographic projection system. This configuration was chosen for this model as that configuration that provides the highest quality image display. At the initiation of this program, consideration was given to construction of a system having a relay optical configuration similar to that currently employed by Ferrante. Such a system is optical efficient. It allows the use of a 2-1/2 inch CRT and map image display screen that results in a compact package. A beam combiner and lens form a virtual image at full scale of the combined data at the output aperture of the display for viewing at an eye relief area 30" from the display aperture.

While the relay system has the advantage that it allows the assembly of a compact display, the image quality is degraded and registration between information from the two sources is not precise. For these reasons, and believing that a significant advantage of the holographic approach is image quality, the relay system was rejected and the direct view system selected. Although the selection was based on the desire to provide a high quality, precisely registered dual display system, there is no fundamental reason limiting the application of the relay system to the holographic projection system if

TABLE 3-1

BEAM COMBINER SPECIFICATION

1.0	Material	Dynasil 4100 or Optical Grade Glass	
2.0	Size	Length:	8.00 in. + 0.00 - 0.020
		Width:	6.00 in. + 0.00 - 0.020
		Thickness:	0.250 in. + 0.000 - 0.030
		Shape:	Rectangle or Octagon with Inscribed Ellipse
3.0	Surface		Both Surfaces Polished Flat to 2 Waves @ 5000 Å over Clear Aperture
4.0	Clear Aperture		Ellipse Corresponding to 5.68 in. dia. beam on plane surface at 45° incidence. This would appear as a 5.68 dia. circle when viewed through the splitter.
5.0	Parallelism		Less than 8 arc minutes
6.0	Transmittance		Narrow pass bands conforming to a P43 phosphor emission spike. It must have a full-width half-power of 100 Å $\pm$ 25 Å and a peak transmittance of better than 75% centered at 5437 Å.
7.0	Reflectance	First Surface:	The reflectance shall be better than 87% for all wavelengths from 4500 to 6500 Å except for the transmission spike specified in 6.0 above.
		Second Surface:	Antireflection coating $R < 0.5\%$ from 4400 Å to 6500 Å
8.0	Incidence		Angle of incidence: 45°

TABLE 3-1 (Continued)

9.0	Field of View	12^{o} total i.e. $\pm 6^{o}$ half-field
10.0	Polarization	Random
11.0	Durability	Both surfaces must withstand cleaning procedure such as immersion in ORVIS without noticeable degradation

it is accepted that the degradation in image quality will be of the nature of that experienced in competing systems.

4.0 RECORDING SYSTEM

4.1 Multicolor Information

Multicolor information is stored using focussed image holograms. A hologram is the recording of an interference pattern formed between an information-bearing object beam wavefront and a reference wavefront. For the formation of a focussed image hologram, the interference pattern is formed in an image plane of the object beam. The recording system, shown schematically in Figure 4-1 and as implemented in our laboratory (Figure 2-3) for this program, employs a spherical reference wavefront to generate the storage interference pattern. The interference of the spherical reference wavefront with the object wavefront produces an interference pattern which is in essence a linear grating. The grating depth (when recorded on a phase medium) or transmission (when recorded on an absorptive medium) is spatially modulated by the imaged information.

The recorded grating when placed in a readout beam similar in construction to the recording reference beam, as shown in Figure 4-2, acts as a diffraction grating, diffracting light down the optical axis of a projection system. The diffraction efficiency is modulated by the grating depth on transmission.

In the recording system of Figure 2-3, a HeCd laser is employed as the coherent energy source. The emission of this laser at 0.488 um matches the spectral sensitivity characteristic of the photoresist recording material. The energy as it exits the laser passes through a shutter and is then split into two components. One component is filtered by the lens-pinhole combination, L_1, and then expanded to fill an object plane. The objects are continuous tone black and white transparencies. The energy, modulated with the information to be stored as it passes through the transparency, is collected and concentrated at the aperture of an imaging lens which images the stored information on the photoresist recording plane.

The second component of the segmented laser beam is filtered and formed to a spherical wavefront by the lens pinhole combination, L_5 , this beam too, is directed to the recording plane interferring with the object beam. To produce the storage hologram, multiple holograms are recorded in a common area by making use of the property that the holograms are essentially linear storage gratings and as such, the readout reference beam must enter the tape at the same reference beam angle used for recording; if the principle ray of the reference beam is rotated in a conical surface which has as the major axis of the cone the perpendicular to the hologram plane (Figure 4-3), upon reconstruction of the stored information energy will be diffracted from the reference beam but it will not be diffracted to the acceptance aperture of the lens system. Hence, an image will not be formed at the readout plane. However, if a second hologram is made over the first hologram, but with the reference beam rotated in the conic surface, rotation of the readout beam through the same angle will produce an image in the image plane.

The three elements of a color separation set are recorded in this fashion in a common 21mm x 21mm storage area on a 35mm holographic storage tape. The principle grating angles with the red information recorded at 0°, are blue, 45° and green, 90°.

Rotation of the reference beam in the developed hardware is accomplished by a beam switching arrangement which directs the reference beam to one of three reference beam forming systems, which in turn steer the beam to the proper recording angle. The arrangement of this beam steering system is shown in Figure 4-4.

In order to produce the butted holograms required to produce east to west image continuity, the holographic storage frames are recorded along the length of the tape strip. Precise advance of the tape strip is afforded by the vacuum check mechanism of Figure 4-5. In the operational system, as many as 32, 21mm frames corresponding to an east to west ground coverage of approximately 3200 nmi, may be butted along the length of a single tape strip

segment. The mechanism is designed to allow butting of the frames with a precision of better than .001" ($\approx$ .023" at the display scale). The chuck system provides a movable slide mechanism that allows the film to be advanced through a frame dimension. In operation, during an exposure, the tape strip is held down to the movable and ground pieces by an applied vacuum. After exposure the tape is advanced by releasing the vacuum on the ground piece, and with the tape still firmly held to the movable piece advancing that piece until it comes in contact with a precision stop. The vacuum is next returned to the grounded piece and released on the movable piece. The movable piece is returned to its original position where a second precision stop seats it at its initial location. A vacuum is then pulled on botn pieces. The tape strip is ready for recording.

4.2 Address and Registration Information

The portion of the hardware described above is used to generate the storage holograms; the remaining hardware, that highlighted in Figure 4-6, is used for application of the edge track address and registration information. The address and registration information is recorded in two edge tracks using a hybrid Fraunhofer-Fresnel hologram. As described previously, this hologram as used for the HHSD application, has the property that if used to record a series of line or point images, those images upon reconstruction, will move as the storage tapes moves in one dimension, while for motion in the orthogonal dimension, these remain stationary. This property is used in the HHSD system to record y-registration information with a hologram in one edge track that responds only to motion in the y-direction, and x-registration information in the second edge track, but oriented so that this hologram responds to x-motion solely.

The x-registration hologram, the hologram that monitors displacement in the east-west direction, is used to monitor the frame position over the extent of the frame motion. The y-hologram, on the other hand, is only re-

quired to monitor limited excursions in the y-direction, i.e., the distance by which the tape is displaced from its nominal position above the tape deck of the transport mechanism. Large excursions in the y-direction are monitored by observing the displacement of the tape transport deck with respect to the optical axis of the projection system. Since the y-hologram is only required to convey limited registration information, it is, in the current system configuration, also used to record frame address data. A series of ten line segments are designated; the first is a sync bit and is a recorded double width line. The remainder are coded (binary) to designate the address of the frame in the viewing aperture. Consequently, upon reconstruction, the x-hologram is read out as a small line segment that is stationary in space as the hologram moves in the north-south direction, but tracks east-west motion. The y-hologram, upon reconstruction, is read out as a series of small line segments that are stationary for east-west motion of the storage tape strip, but track the limited motion of the tape strip in the north-south direction. The sync pulse is always present; the address bits vary as the tape strip is advanced from frame to frame.

In the current recording process, the multiple bit y-address hologram is recorded by recording each bit in sequence and can require as many as eleven separate recordings. While there is an advantage to recording the data serially, intermodulation between bits is eliminated, the recording operation becomes protracted. In addition, care must be taken to ensure uniformity of the recorded information by matching the recording times to the photoresist sensitivity and thickness and number of bits to be recorded.

With the present address and registration recording system configuration, it has been impossible to generate the y-address hologram with any degree of consistency. The sample tapes delivered under this program are the result of approximately 30 recording sequences executed in an attempt to produce the 4-10 frame tape strips required to present a 4 x 4 map array. As a consequence of the difficulties encountered in producing the tapes delivered under the current

program, it is our belief that the address recording system must be drastically revised.

The sequencer presents a second problem that has limited our ability to consistently record good address and registration holograms. Noise in the sequencer limits the effectiveness of the system. Although effort was devoted during the course of this program to the elimination of this noise which produced spurious control signals disrupting the recording process, the program was handicapped by limited resources; the problems were not successfully resolved.

The implementation of serial bit recording hardware for recording the edge track address information was a decision made with forethought. Previous programs had used parallel recording techniques that were limited by intermodulation effects. Despite problems encountered during this latest program, it is still our belief that for the annotation of focussed image tape strips the serial recorder of the hybrid Fraunhofer-Fresnel hologram is the optimum addressing technique.

To achieve consistent results, however, the control system used to sequence the steps of the recording operation must be improved by first upgrading the design of the retrieval system to eliminate noise problems, and second to directly monitor laser energy at the film plane to control the exposure rather than monitoring the exposure time. In addition, it will be necessary to repeat a series of photoresist calibration experiments performed on previous programs with, in this current case, particular emphasis on the address recording configuration to determine the correct recording levels for each multiple bit groups to be recorded.

While thought was given to performing this experiment during the course of the current program, the magnitude of the effort required was beyond the current resources.

5.0 DISPLAY HARDWARE

5.1 Configuration

As previously indicated, the display hardware assembled under this contract combined techniques, and to a large extent hardware, developed under previous programs, to produce a laboratory system capable of displaying annotated multicolor information.

The display constructed in the configuration of Figure 2-1 is a combined display having the characteristics listed in Table 2-1. The multicolor information is displayed by interrogating and projecting the information stored on the holographic tape strips produced using the hardware previously described. The elements of this projection subsystem are highlighted in the schematic of Figure 5-1 and the equipment photograph of Figure 5-2.

Annotation information in this demonstration system is generated by a direct view CRT subsystem. The CRT, a modified DuMont KC2980 having the characteristics listed in Table 5-1, is operated in a stroke mode to allow alphanumeric and graphical annotation of the stored multicolor information.

The combined display in this laboratory configuration, is packaged in three assemblies. The head end of the display has the outline configuration shown in Figure 5-3. It provides a 5" circular viewing aperture.

A second package, shown in Figure 5-4, consists of a 5', 19" relay rack housing the support electronics. Contained within this rack is the holographic tape transport servo electronics and power supplies; commercial grade, high performance CRT drive, deflection and power supply electronics to drive the CRT in the stroke mode; and a brightness control for the holographic projection source.

A third package contains the deflection amplifier for the CRT system.

TABLE 5-1.

CATHODE-RAY TUBE CHARACTERISTICS (STROKE MODE)

CHARACTERISTICS	KC2980 (Modified)
Maximum Diameter	5.75"
Active Diameter	5.00"
Focus Method	Electrostatic
Deflection Method	Magnetic
Deflection	45^{o}
Tube Length (including pins)	9.31"
Line Width	11 mils @ CRT faceplate
Light Output	2,000 ft-l @ CRT faceplate
Writing Speed	20,000"/sec @ CRT faceplate
Phosphor Type	P43 (High efficiency)
Refresh Rate	60 Hz
Accelerator Voltage	15 kV
Accelerator Current	150 ua
Limiting Resolution (Assuming Gaussian spot size)	4 line pair/mm or 500 resolvable TV lines
Min Char Size (@7 line/char)	77 mils
Max # of 7 x 5 char/sec (1)	52,800 char/sec
Max # char/frame	880 char/frame (2)
Max length of Graphics	268"

Note (1) $$\# \text{char/sec} = \frac{\text{Character Perimeter (inches)}}{\text{Character}} \times \frac{1}{\text{Writing Rate}}$$

$$\text{Eg: } \#\text{Char/sec} = \frac{[7 + 7 + 5 + 5]\ 11 \text{ mils}}{1/20{,}000 \text{ inches/sec}} = 52{,}800$$

(2) Limited by maximum writing rate and considered for case where there are no spacers between characters.

The program structure limited repackaging existing hardware. As a consequence, the head end of the display employed a previously implemented source and transport mechanism fixing the size of the rear of the display. The direct view CRT approach assumed for this program coupled with the requirement for a 5" diameter viewing aperture established the display height and length.

No attempt was made to minimize the package size of the support electronics; the limited resources of the program required that the breadboard transport system of Figure 5-5 be mounted with as little modification as possible in the support electronics rack. The CRT electronics was purchased as a system meeting the program drive requirements. A cost trade-off was established and a relatively inexpensive but unfortunately, large commercial electronics package secured.

5.2 Multicolor Display Subsystem

The holographic multicolor display subsystem, Figure 5-2, is comprised of the component elements tabulated in the first part of Table 5-2. These elements are discussed briefly below.

Source Assembly - The source assembly, Figure 5-6, was originally assembled under Contract #N62269-76-C-0134 . It is a multi-element source in the configuration of Figure 5-7. Six GE 1962, 50 watt lamps are employed to read out the three overlayed focussed image holograms used to store the three elements of a color separation set associated with a stored map segment. The bulbs are located at the focus of a parabolic reflector. Two reflector-bulb assemblies are paired and filtered with filters having the characteristics shown in Figure 5-8 to produce two red, two blue and two green readout beams positioned and shaped as shown in Figure 5-7. The multiple beams allow simultaneous readout of the red, blue and green holograms - the dual sources are positioned to diffract energy from the readout beams down the optical axis of the projection lens to provide a full color image restoration.

Transport Mechanism - The transport mechanism, Figure 5-9, operates as a reel-to-reel drive system when operated in a high speed retrieval mode.

TABLE 5-2

HOLOGRAPHIC HORIZONTAL SITUATION DISPLAY COMPONENTS

Holographic Projection System Elements

1. Projection Source Assembly and Brightness Control
2. Projection Lens/Rotating Prism
3. Folding Optics
4. Directional Viewing Screen
5. Beam Combiner*
6. Transport Mechanism
7. Transport Servo Control System (including film position sensors)
8. Image Rotation Servo Control System
9. AIDS Interface Logic (Low Bandwidth Data Bus)
10. Thermal Control Subsystem*
11. Power Supplies

Dynamic Annotation Subsystem (CRT)

1. AIDS Interface Logic (X3 High Bandwidth Data Bus)
2. Sync separation and deflection circuitry
3. Video Processor and Z Axis Drive Amplifier
4. Phosphor Protection/Focus Modulation
5. CRT Assembly (Tube, Yoke, Shield)
6. Beam Combiner
7. Thermal Control Subsystem
8. Power Supplies

*Common to Dynamic Annotation CRT and Holographic Projection Systems

When low speed tape motion - motion such as desired when the system is operated in the tracking mode - is required, the reel torque applied by the two reel drive motors is balanced, and a pinch roller engages a capstan driven by a stepping motor.

The characteristics of this transport mechanism and the supporting servo system are described in the Final Report of Contract #N62269-C-0609 and N62269-72-C-0462. This hardware, developed during these earlier programs was used with little modification during the current program.

Reviewing the system performance at the completion of this current program, the following is to be noted:

(1) The system effectively demonstrates the high speed retrieval and tracking mode operating parameters specified in Table 2-1.

(2) The gear ratio associated with the stepping motor used to drive the tape at low speed should be increased. As currently implemented, for simulated aircraft speeds of Mach 0.5 to 1.5, the motion at the display scale is intermittent with an incremental image advance of .010 inches occuring at a 0.8 Hz to 2.5 Hz rate. The effect is not pleasing.

(3) Difficulties in producing reliable address holograms are reflected in the reliability of the operation of the transport servo system. While sample tapes supplied with the system allow system operation, the development of future systems should allow not only a refinement of the method of recording the address and registration holograms, but also the method of sensing the recorded information.

(4) A transport redesign should be executed for a flight qualified system that eliminates the timing belt drive assembly of the current mechanism.

Imaging Lens - The imaging lens is an f/2.5 lens having a 40 mm focal length. The system is operated at a magnification of 21.8 from the holographic storage

plane to the viewing screen. At this magnification a 5.83 mm diameter circular area of the hologram is imaged to the 5" diameter viewing screen. Operating at these conjugates the lens produces a 40% MTF response at 8 lp/mm as measured at the viewing screen. An advantage of the holographic approach is that this lens may be of a high f/# that is relatively inexpensive as compared to high brightness film projection system lenses.

Pechan Prism - A Pechan prism having the configuration of Figure 5-10 is included in the optical path to allow rotation of the optical image. The Pechan prism has the property that rotation of the prism assembly produces a rotation of the optical image at twice the angular rate.

The nature of the holographic projection system, i.e., the complexity of the off axis source and the requirement that the multiple reference beams strike the holographic surface at prescribed angles with respect to the grating orientation of the holograms, makes it impractical to rotate the storage medium.

The insertion of the prism in the optical path is a factor that has a direct impact on the projection path length. The divergence of the beam passing through the prism is limited by the acceptance and exit apertures of the prism, the effective path length through the prism, and the size of the unobstructed beam entering the prism. For the geometry of the laboratory display, the divergence is 8.17 degrees, which for a magnification of 21.8 dictates a minimum lens to image distance of 35 inches. To reduce this path length it is required, a recommendation for future system implementations, that a relay lens system be constructed which allow positioning of a Pechan or dove (an alternate method of producing an image rotation) in a collimated bundle within the lens, consequently allowing the assembly of a lens-prism combination having, a reduced focal length.

Viewing Screen - The energy exiting the prism (or lens-prism combination) is directed toward the viewing screen; folding mirrors are included in the optical

path to allow a reduction of the length of the display. The viewing screen, as illustrated in Figure 5-11, consists of a pair of condenser lenses that image the exit aperture of the projection lens to an eye relief area at a 30-inch viewing distance from the display screen (in the configuration of Figure 5-3 inches from the front of the display). If the condensers alone were used, the display would have a high brightness but a limited eye relief area.

In the laboratory system, the eye relief area is spread over an eight-inch diameter viewing area by a diffusion plate located between the condenser lens and at the image plane of the projection lens. The diffussor plate consists of randomly placed spherical indentations .3 mm in diameter but .1 mm deep in a glass plate. (A technique has been devised for duplicating this screen in plastic.) The resulting concavities form small lenslets having .6 mm focal length, resulting in a spreading of the energy over the eight-inch eye relief area as shown in Figure 5-11.

The diffusion plate is bonded to one of the condenser faces with the result that the screen assembly consists of four air to glass interfaces. The interfaces are AR coated. The result is a screen having a controllable gain (during manufacture by controlling the lenslet diameter) and a low reflectivity. It is a screen ideally suited to rear projection viewing in a high brightness environment of an aircraft cockpit.

Beam Combiner - The final element of the optical projection system is a dichroic beam combiner. The beam combiner is the only element of the system that is shared with the CRT dynamic annotation system.

The beam combiner merges the CRT and the projected color images. The characteristics of the beam combiner were presented in Table 3-1.

The system is designed to pass the narrow green spike of the P-43

phosphor, the phosphor used on the annotating CRT, while reflecting the remainder of the visible spectrum. As a consequence of this combiner, the energy passing through the directional viewing screen with the exception of that in the narrow green transmission bond is reflected by the combiner toward the eye relief area.

To compensate for the loss of green energy in the reflected path as a result of the beam combiner operation the green energy content in the image is boosted during the holographic recording process.

5.3 Dynamic Annotation Subsystem

Dynamic annotation of the multicolor information is provided by a direct view CRT system. In the delivered laboratory system, a modified DuMont CRT driven by an Infodex PD1000 stroke generation system comprises this subsystem.

Specifications of the modified CRT were tabulated in Table 5-1. Specification of the drive hardware is tabulated in Table 5-3. The system is designed to directly interface with the Kaiser Model 2001 character generator.

The CRT is located behind the beam combiner at a distance equal to the virtual image of the viewing screen of the holographic projection system. The CRT and display screens appear to be in the same plane.

The contrast of the CRT can be greatly enhanced by the addition of a narrow band optical filter having the characteristics of Table 5-4. Such a filter is manufactured by MetaVac Corporation of Flushing, New York. With the MetaVac filter in place, the display could be viewed easily in a 10,000 ft-Lambert environment. The contrast of the CRT system was severely reduced with the filter removed, causing a reduction of the ambient illumination to approximately 4000 to 6000 ft-Lamberts for acceptable viewing. The filter was borrowed from MetaVac for demonstration and contrast evaluation.

The CRT, deflection yoke, high voltage supply and phosphor protection circuitry are located in the head end of the display. The deflection amplifier

TABLE 5-3

CRT DRIVE ELECTRONICS CHARACTERISTICS

SPOT SIZE (Note 1)	
Center of CRT -- PD1000/M17	.20 mm
Within Quality Circle - PD1000/M17	.30 mm
LIGHT OUTPUT	2000 ft. - Lambert @ 20,000 in/sec writing rate -- 60Hz refresh
SETTLING TIME (to 0.1% anywhere within quality circle)	10.0 μ seconds max. for 1/2 screen step
SMALL SIGNAL BANDWIDTH	650kHz min.
USEFUL DIAMETER	12 cm
TUBE SIZE	5 inches
FACEPLATE	flat
DRIFT (Notes 2, 3)	$\pm$ 0.15%
TEMPERATURE STABILITY (Note 3)	0.04%/^{o}C max.
LINEARITY (Note 3)	0.5%
REPEATABILITY (Note 3)	$\pm$ 0.1%
CONTROLS (Front Panel)	
Horizontal and Vertical Centering	
Focus	
Brightness	
DEFLECTION INPUT	
Amplitude (full scale deflection)	$\pm$ 10v Differential
Impedance	1000 ohms
UNBLANKING INPUT	
Unblank Level	2.5 to 5v
Blank Level	0 to .4v
AC POWER INPUT	
Voltage	105 to 125 volts
Frequency	57 to 63Hz
PHOSPHOR PROTECTION	Rate Sensing

TABLE 5-4

META VAC FILTER SPECIFICATIONS

COATING:	Meta Vac 7028 high efficiency anti-reflective coating; peaked for P-43, two sides
PEAK TRANSMISSION:	18.5% ± 1.5% @ 545 nm
DIAMETER:	5.09 ± .015 inches
THICKNESS:	0.190 ± 0.015 inches
CATALOGUE NUMBER:	Meta Vac 1598 - 18.5 Contrast enhancement filter

is a separate package that must be located within four feet of the display. The signal processing,deflection signal generation electronics as well as the remaining system power supplies are located in the electronics rack of Figure 5-4.

The dynamic annotation system of the laboratory reader delivered under this program is a stroke system with a maximum writing rate 20,000 inches/sec when called upon to produce .006 inch line having a brightness of 2000 lumens/meter^2. As indicated above, at this brightness with a narrow band enhancement filter in place, the display can be viewed in a 10,000 foot-Lambert environment. However, current HHSD requirements as typified by the F-18 and AIDS programs require 575/875 raster displays that allow not only the presentation of alpha-numeric and graphical information, but also the display of continuous tone sensor information.

The requirement to produce a raster impacts on two aspects of the system implementation. First, a higher brightness CRT is required and secondly, the electronics package must, of course, be designed for raster operation.

Watkins-Johnson makes a line of high brightness tubes that should be evaluated for this application.

The design of raster electronics for the CRT drive would allow the implementation of a compact display of reduced power. It is believed that such a system could be implemented with a power dissipation of less than 100 watts for the dual raster mode of operation. It must be remembered that the alpha-numeric annotation information must now be generated in the raster mode, and that this generation process becomes complex particularly when it is required to rotate the map information in registration with the multicolor information.

A possible solution to the complexity of generating the alpha-numeric information in a raster display is to generate this information using a stroke system during the vertical blanking period. Such a system calls for large deflection power and as a consequence, will significantly increase the size and power requirements of the deflection electronics. Such an approach, while noted here, is not recommended.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The program objective, to provide a display system that fully demonstrated the HHSD characteristics, were not fully achieved. Display hardware in the configuration of Figure 2-2 was assembled. As implemented, both multi-color map information and dynamic annotation information could be presented for easy viewing in a 10,000 ft-Lambert environment. However, the source material generated for use with the display could not, with the resources available under the current program, be generated with a consistency required to produce butted map strips of uniform quality.

The source material tape strips generated during the course of this program were deficient in two respects: First, in a majority of the tapes generated, precise butt joints could be established; there was, however, noticeable hue shift across the joints. Secondly, it was not possible to record, with consistency, frame address holograms of uniform quality. The hue shifts were due in part to drifts of laser beam power during the recording cycle. An integrating exposure control system would correct this problem. Correction of the address recording system is a more difficult problem. Thorough evaluation of this system has led to the recommendation that for future programs, the method of recording and sensing this information be extensively revised.

When proper interpretation of edge track information was achieved, the transport mechanism and servo system performed well. High speed retrieval and tracking mode operations were demonstrated. System performance could be improved by modifying the gear ratio between a driving stepping motor and tracking mode drive capstan to eliminate an intermittent motion problem when the system is at simulated aircraft speed of Mach 0.5 to 1.0.

The resolution of the map display at the display scale is in excess of 6 lp/mm at a 40% MTF response level. The limiting resolving power of the eye at a viewing distance of 30 inches, is of the order of 4.5 lp/mm.

The head end of the display system, as assembled under this program, in a configuration that allows direct viewing of the CRT, is 11.4" (H) x 7.3" (W) x 22.5" (D). The display height, a dimension that is prohibitive for many HSD applications, is a direct consequence of a decision made early in the program to directly view both the CRT faceplate, the annotation data source, and the viewing screen of the projection system. If the display size is to be reduced, a sacrifice must be accepted in image quality, if a relay system is used; resolution of the dynamic annotation data, if a lens - projection system is used (as shown in Figure 6-1); or a new device (technology) is required, perhaps an in-line liquid crystal modulation system, for introduction of the dynamic annotation data.

The laboratory display system assembled under this contract employs a stroke system for introduction of dynamic alpha-numeric and annotation data. The current system is not capable of producing a continuous tone raster display. There are, however, higher brightness tubes made by Watkins-Johnson that would allow a raster presentation.

The package delivered under this program is designed as a laboratory model. No attempt was made to miniaturize or optimize the electronics. Redesign of both the CRT (preferably in a raster mode) and transport servo electronics, and the utilization of a consolidated power supply would allow packaging of the display with discrete components in a compact 2-box flight configuration. A hybridized or large scale integration, LSI, development would allow the implementation of a single package configuration.

As currently implemented, the system interfaces are those tabulated in Table 6-1 . The retrieval system is designed to be driven directly from a Model 2001 Kaiser character generator. The retrieval system operation is controlled from a front panel switch register. Computer control of the retrieval system is possible by direct entry through the digital interface. Sample

programs are available for the NOVA 1200. Interface modification will be required for operation on the NADC-AIDS data bus.

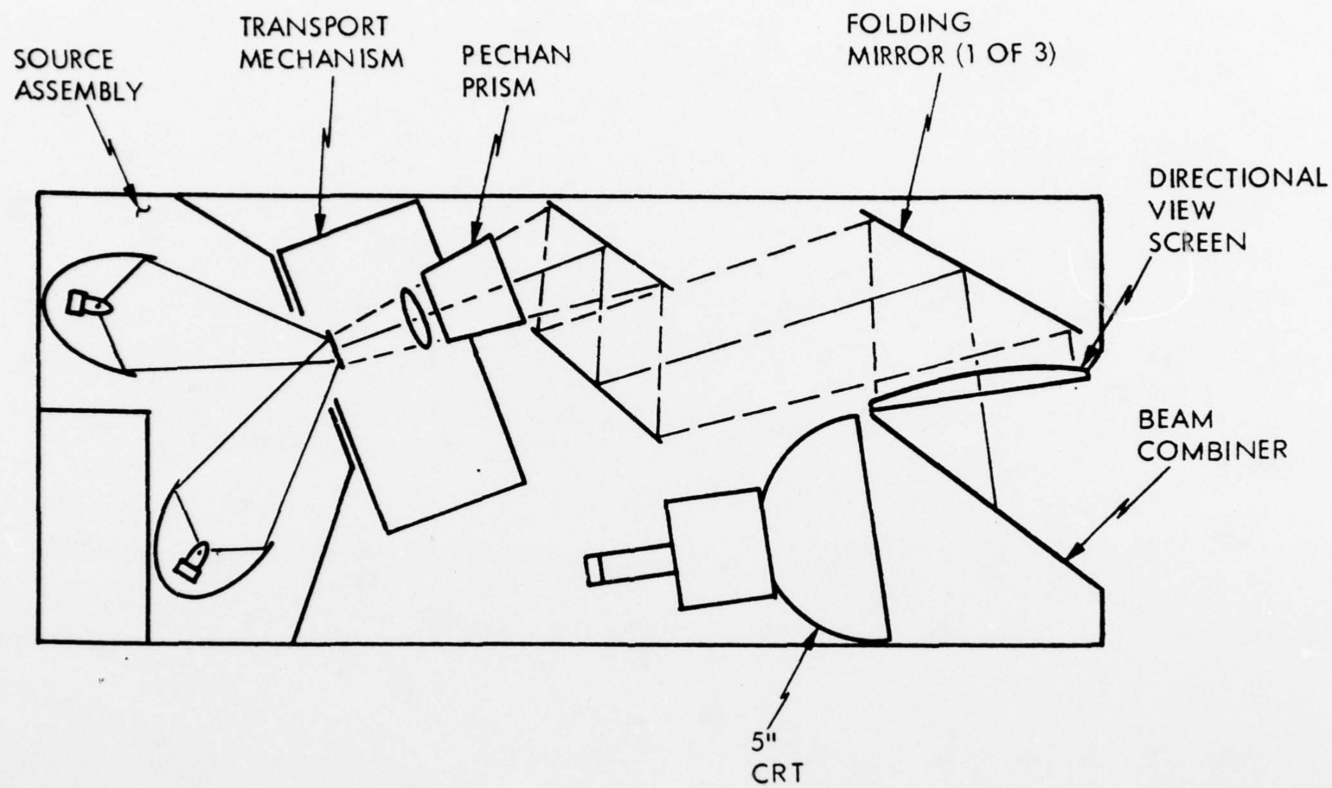


FIG. 2-1. DISPLAY SYSTEM CONFIGURATION

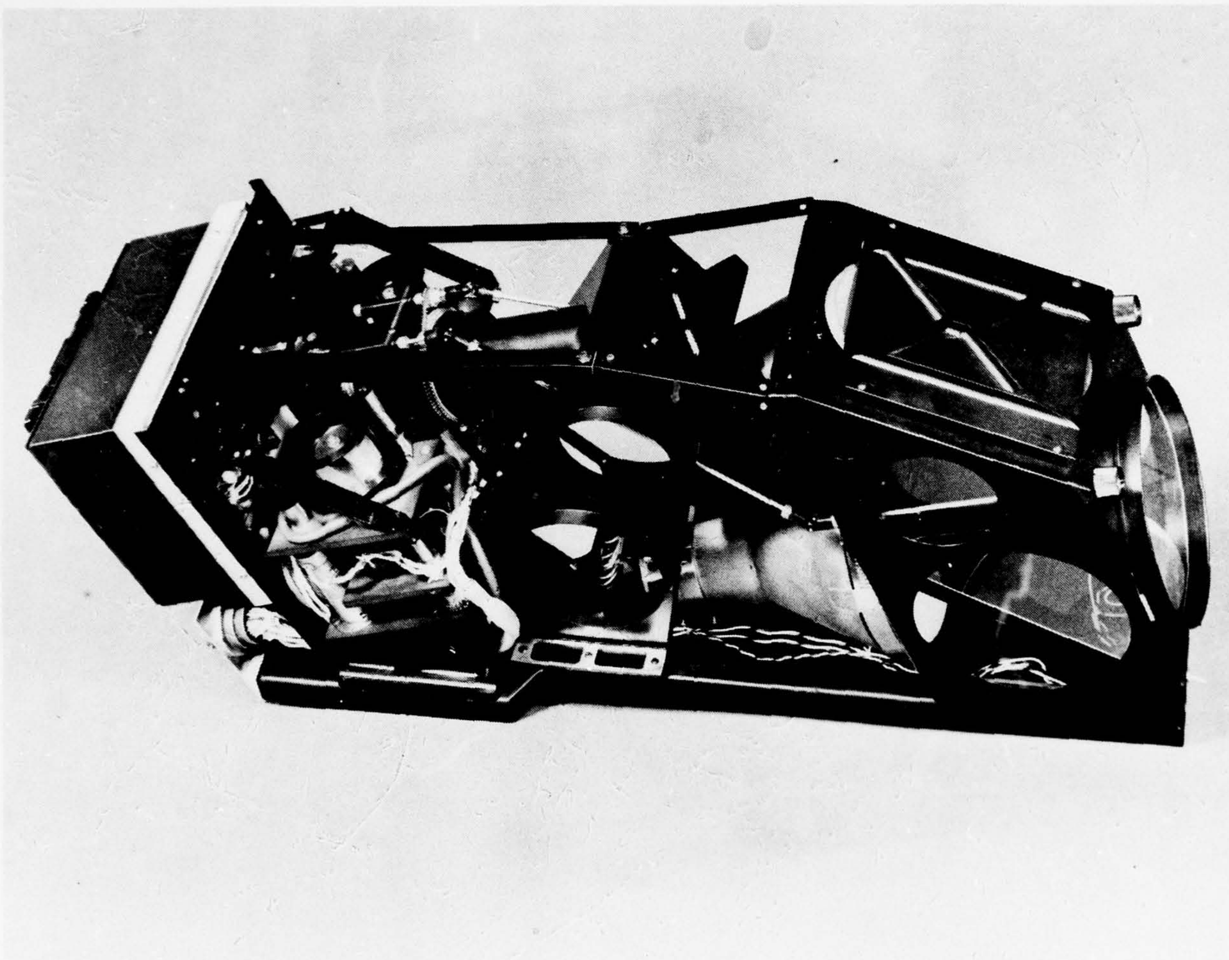


FIG. 2-2. IMPLEMENTED DISPLAY HARDWARE

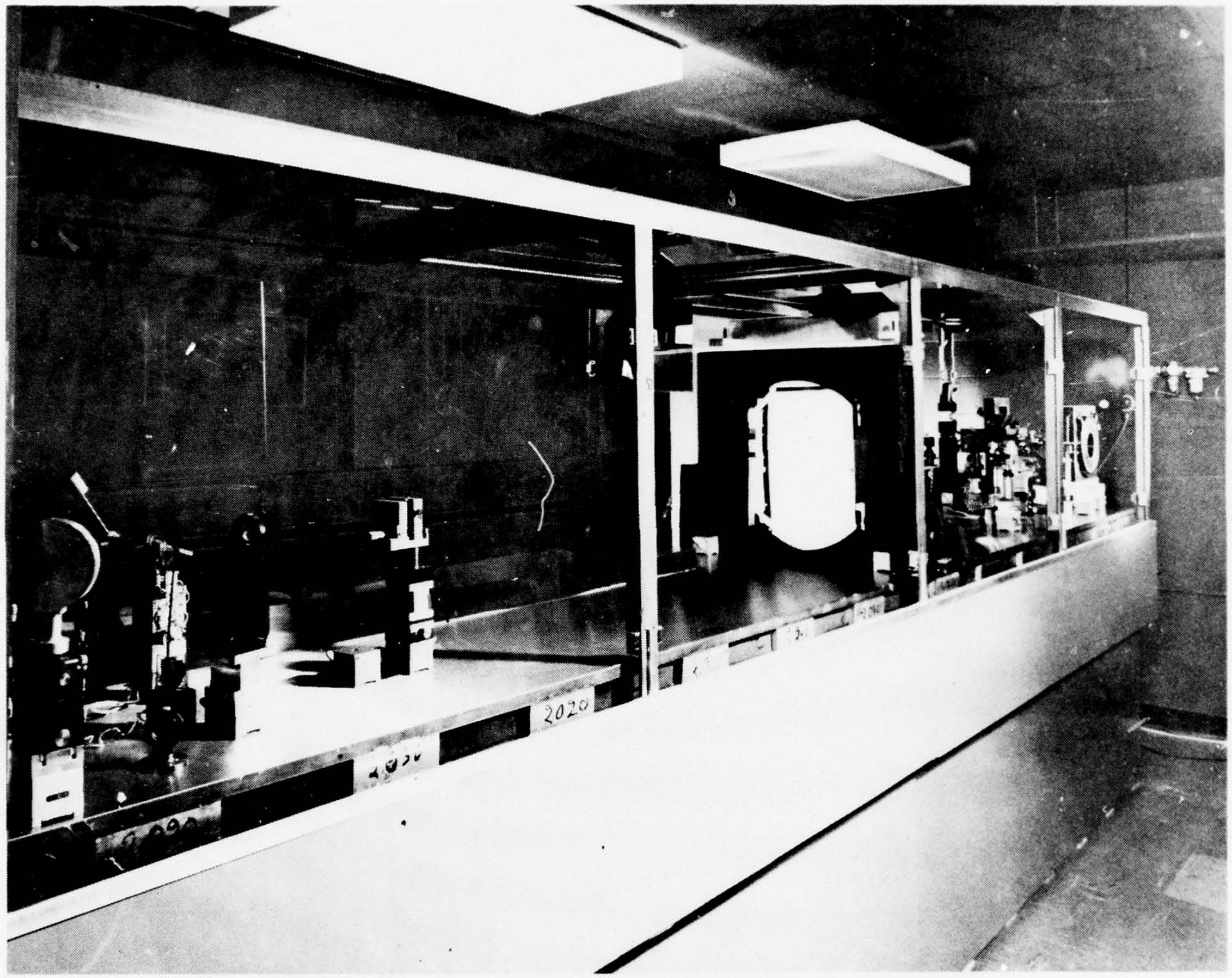


FIG. 2-3. RECORDING HARDWARE

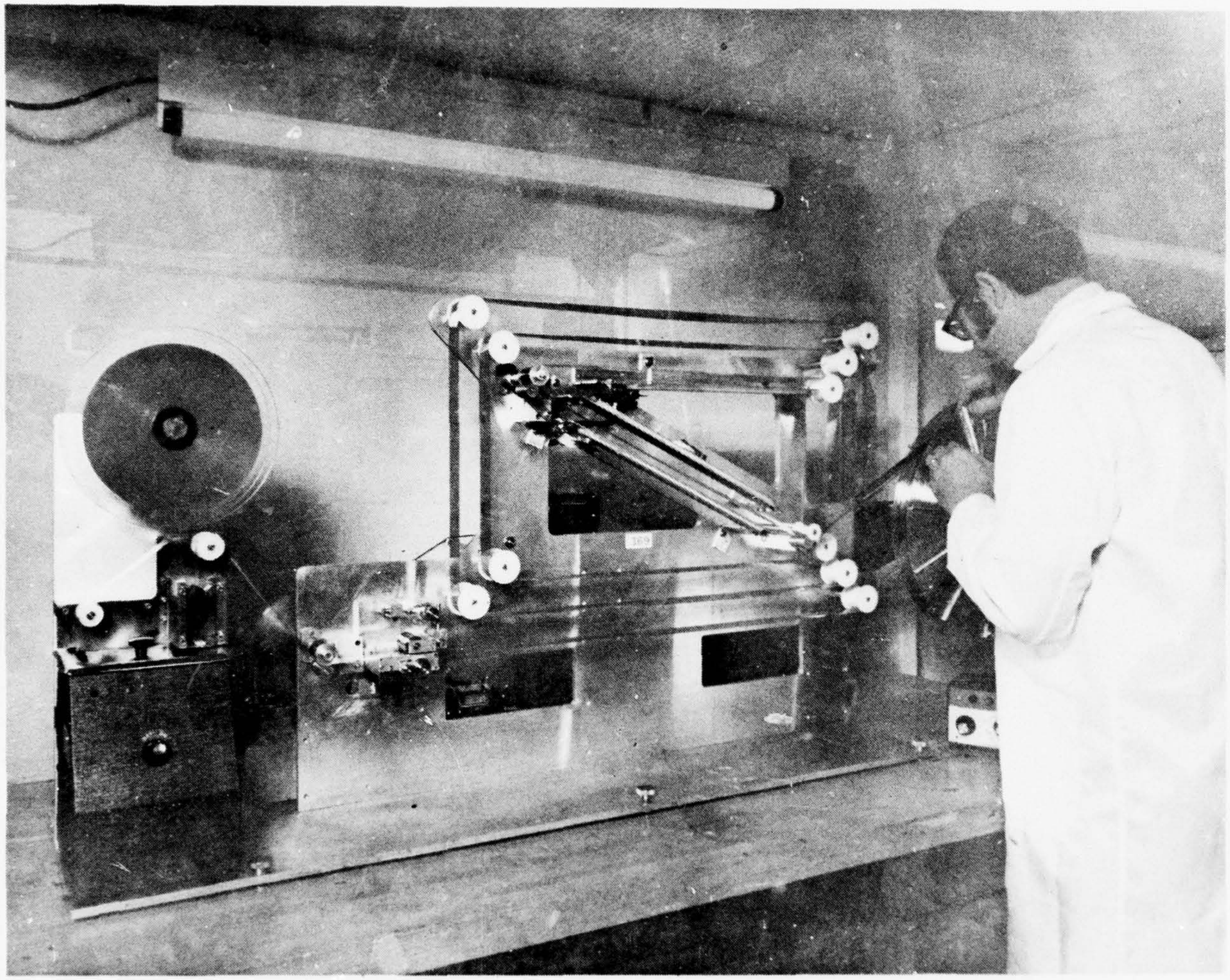


FIG. 2-4. COATING HARDWARE

FIG. 2-5. LEXAN STORAGE TAPE

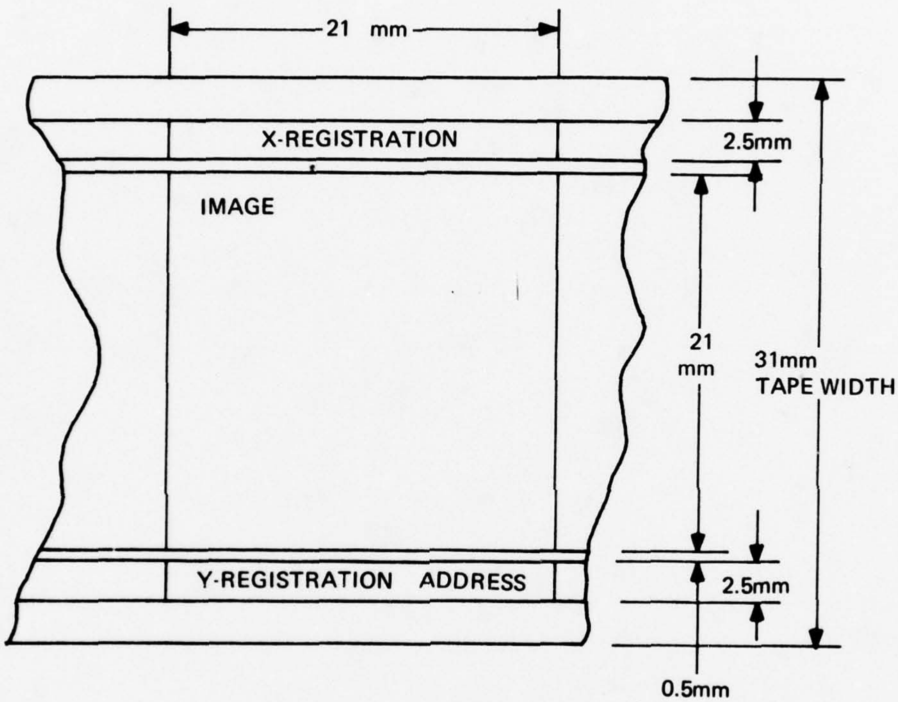


FIG. 2-6. STORAGE TAPE CONFIGURATION

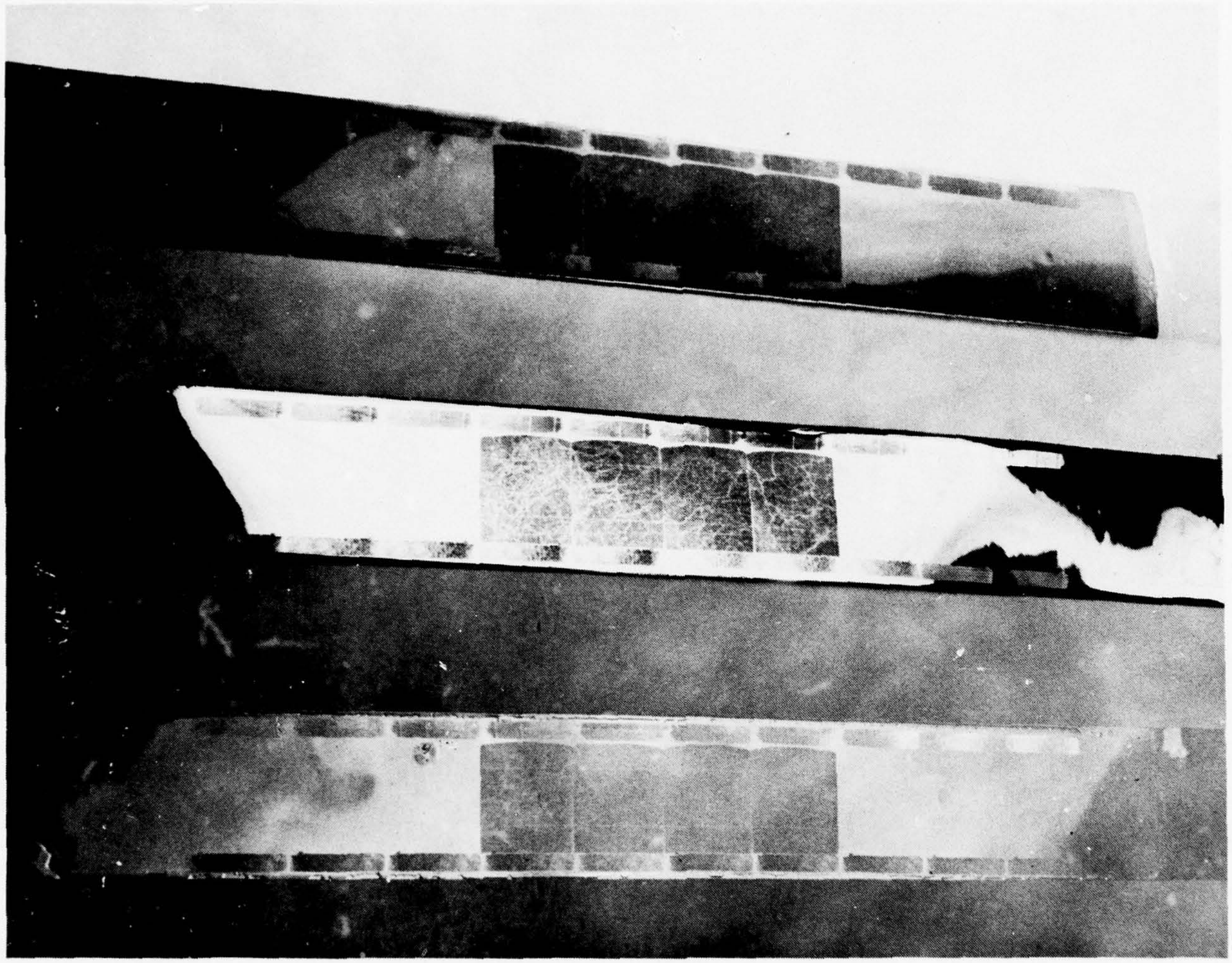


FIG. 3-1. DUPLICATION PROCESS TAPES

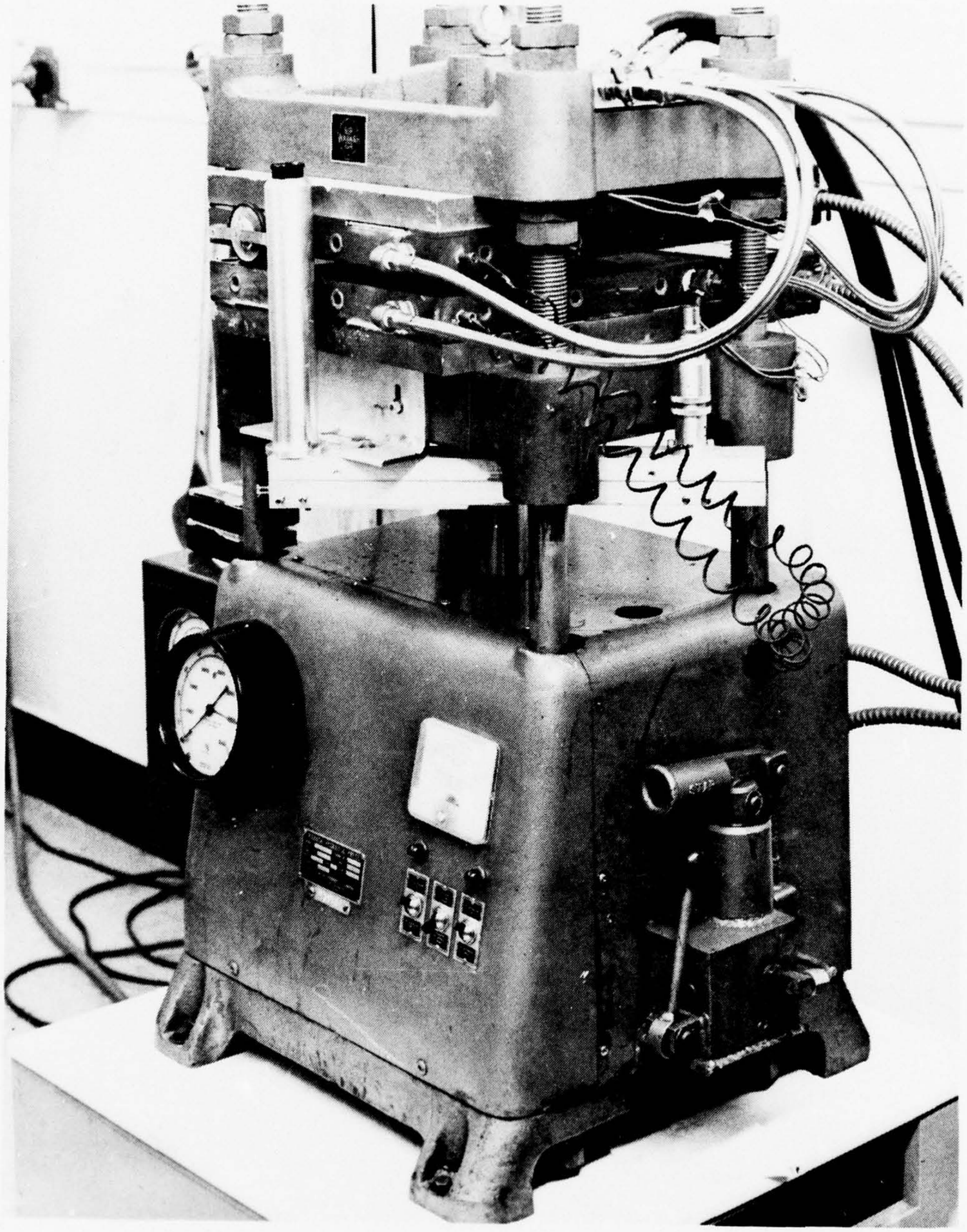


FIG. 3-2. PRESSING HARDWARE

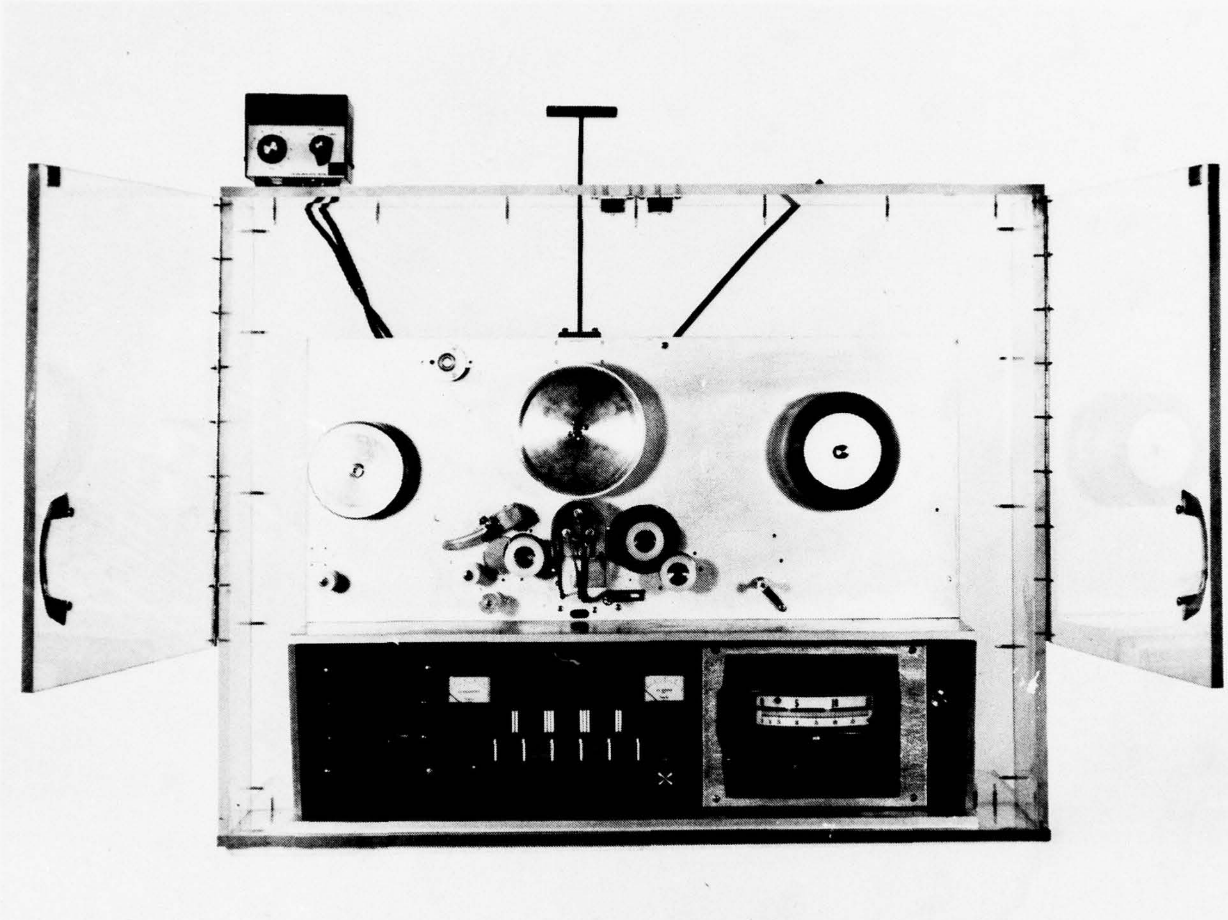


FIG. 3-3. SINGLE SIDED CONTINUOUS PRESS

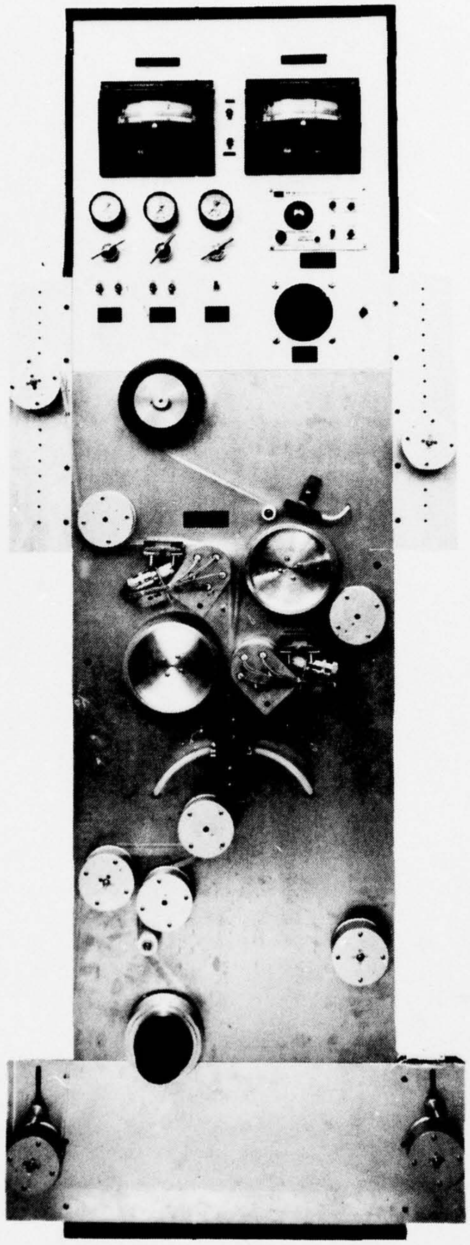


FIG. 3-4. DOUBLE SIDED CONTINUOUS PRESS

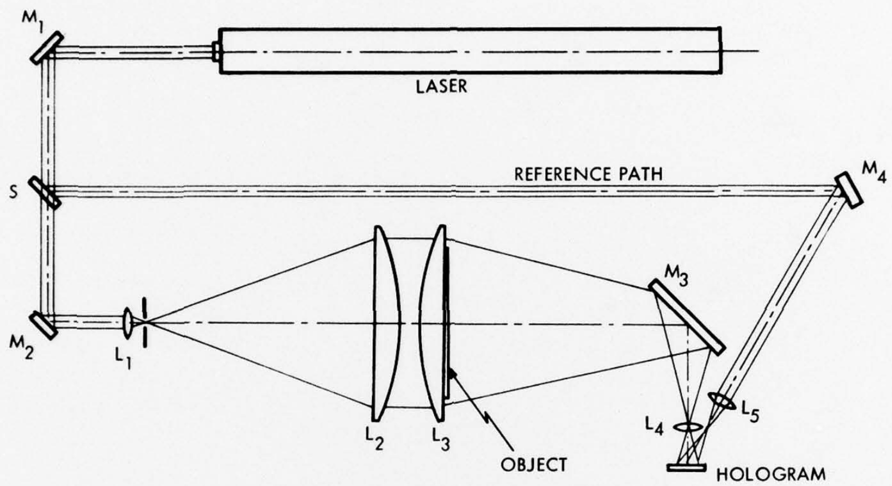


FIG. 4-1. RECORDING SYSTEM SCHEMATIC

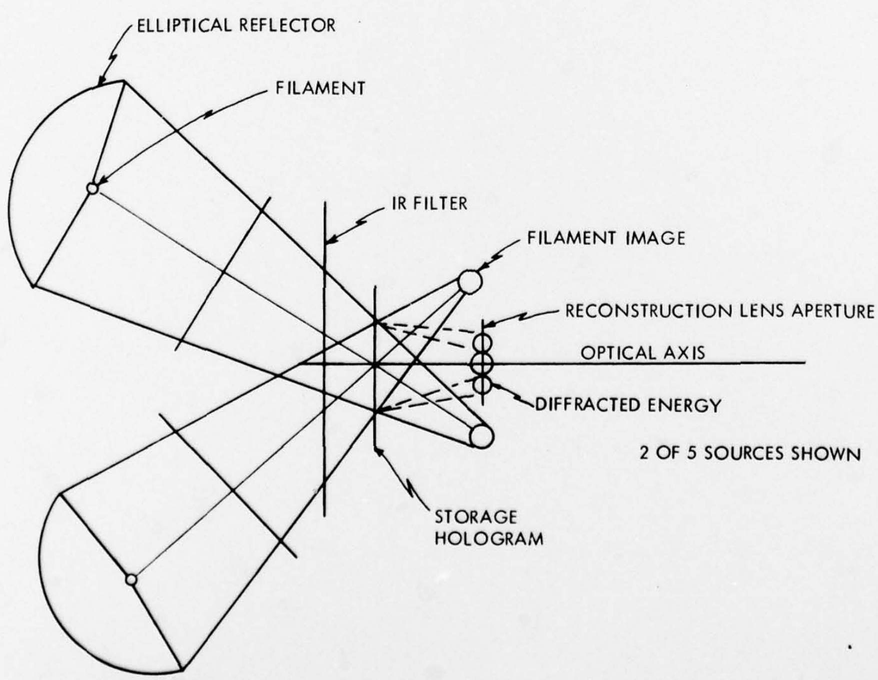


FIG. 4-2. READOUT SCHEMATIC

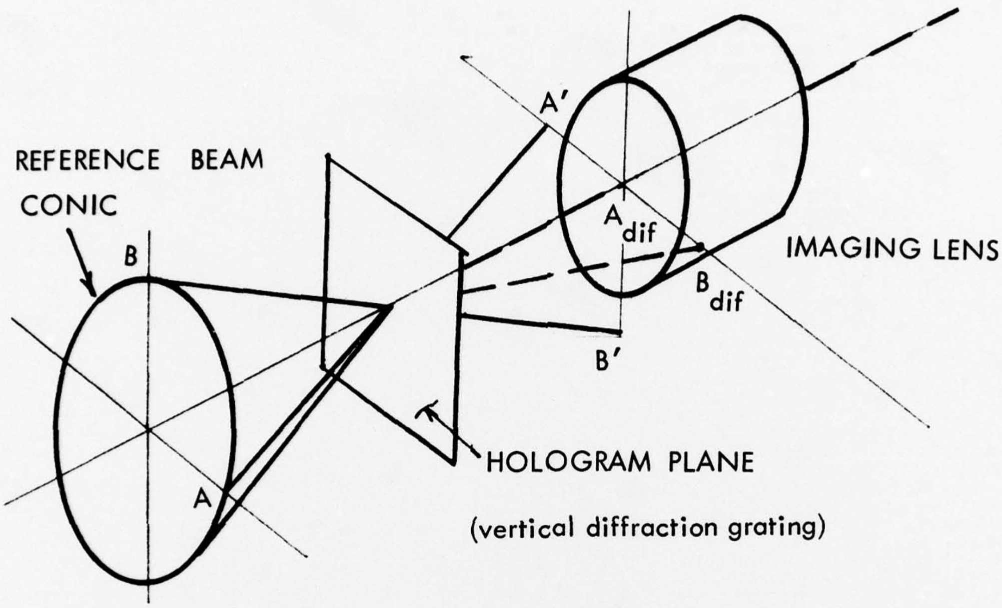


FIG. 4-3. MULTICOLOR RECORDING SCHEMATIC

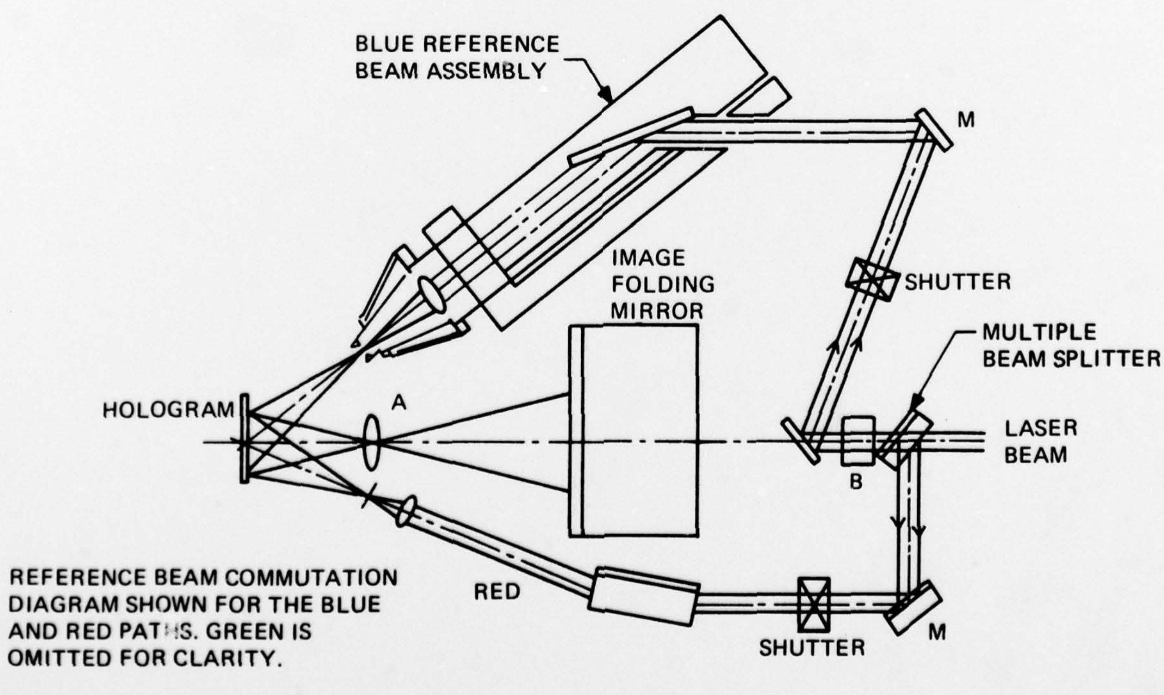


FIG. 4-4. RECORDING SYSTEM BEAM STEERING HARDWARE

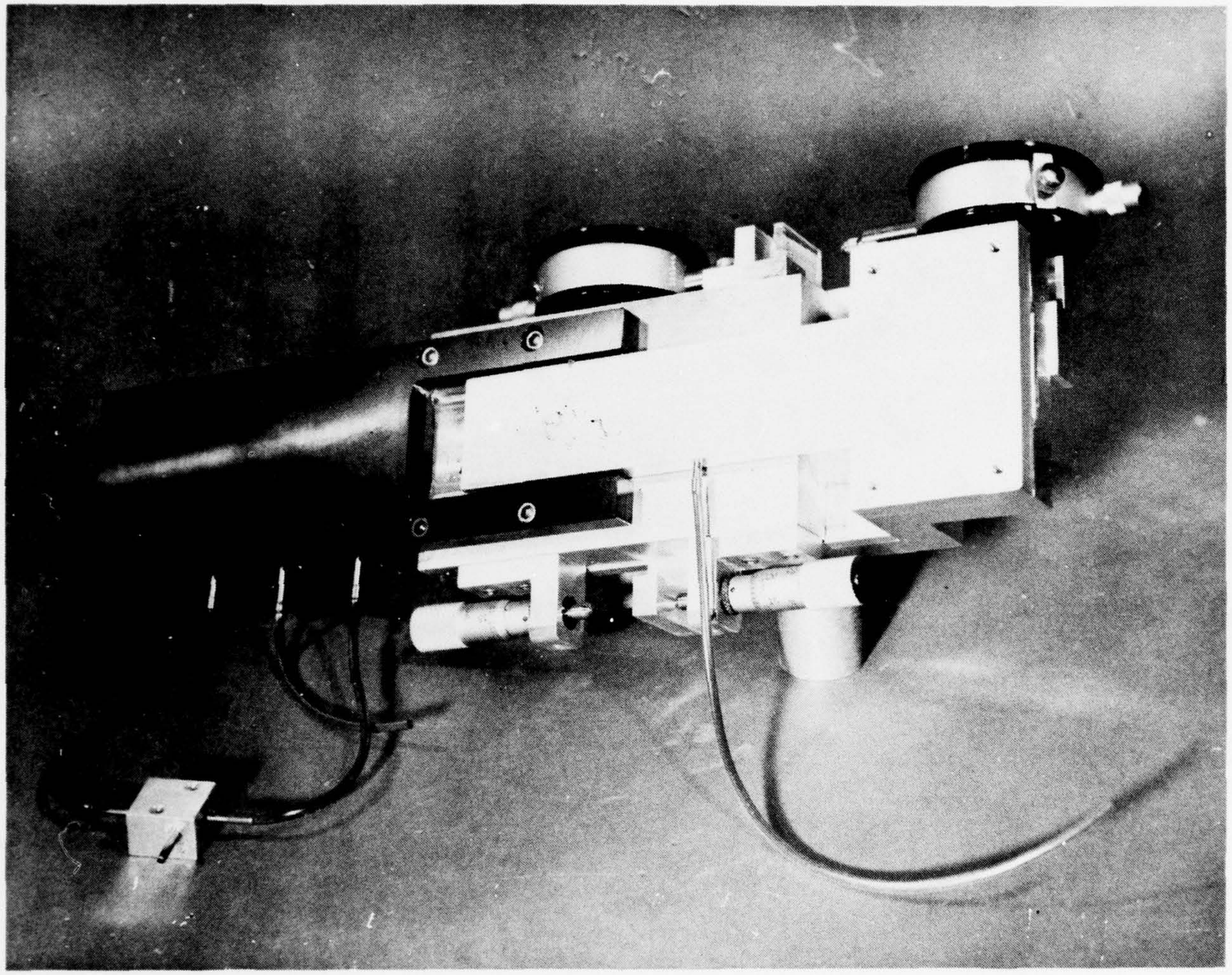


FIG. 4-5. FILM ADVANCE MECHANISM

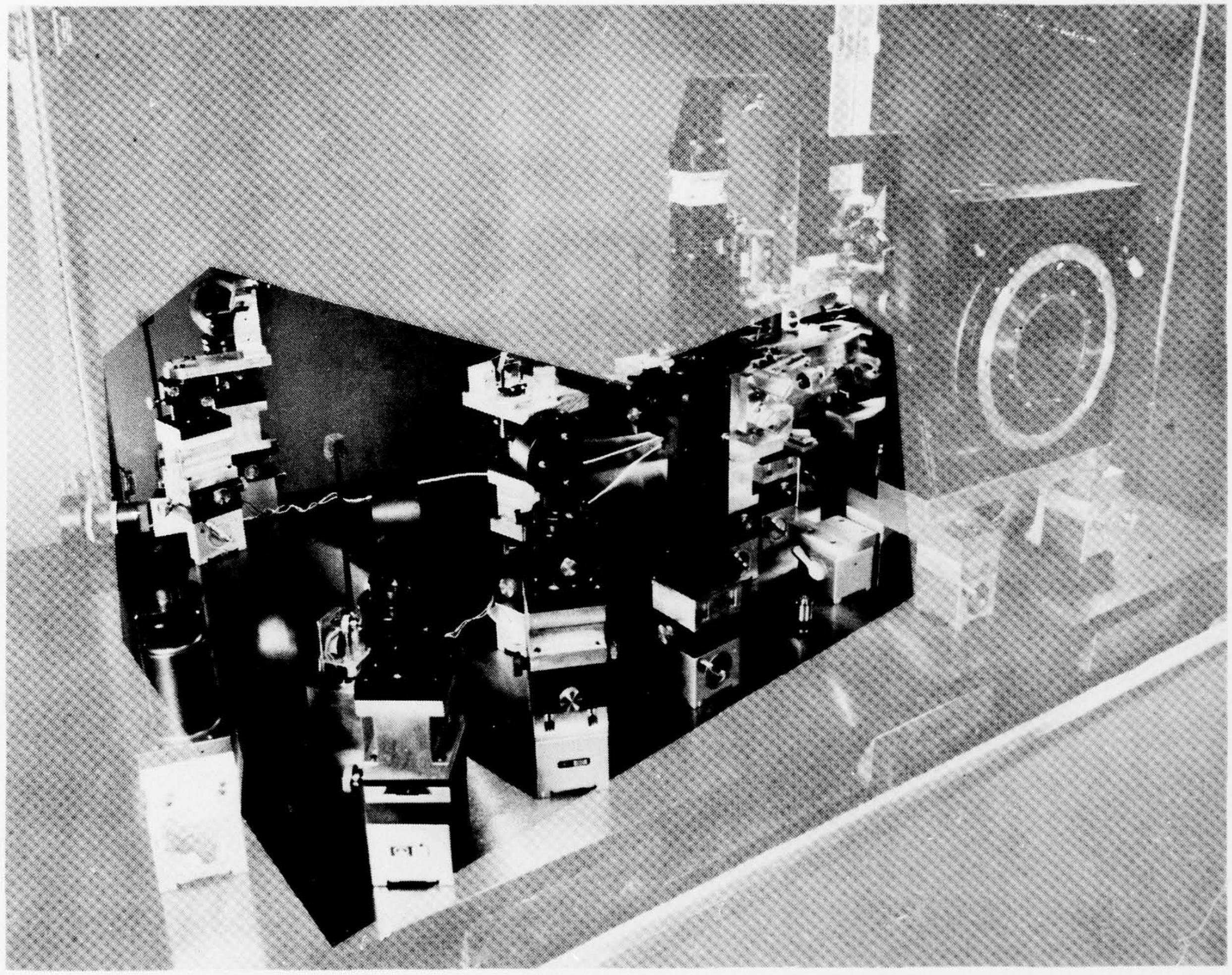


FIG. 4-6. ADDRESS AND REGISTRATION RECORDING SUBSYSTEM

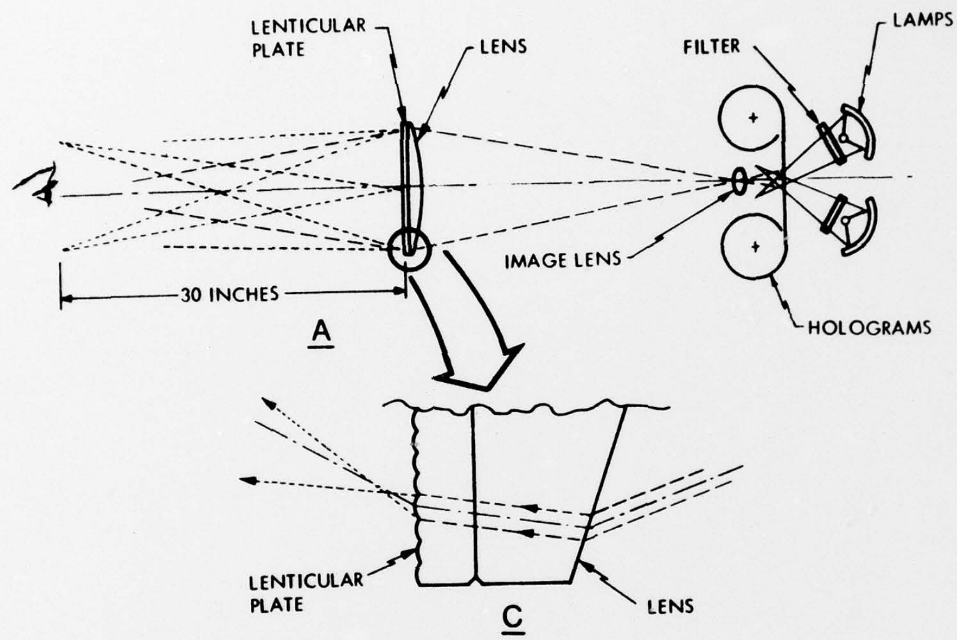


FIG. 5-1. HOLOGRAPHIC PROJECTION SYSTEM SCHEMATIC

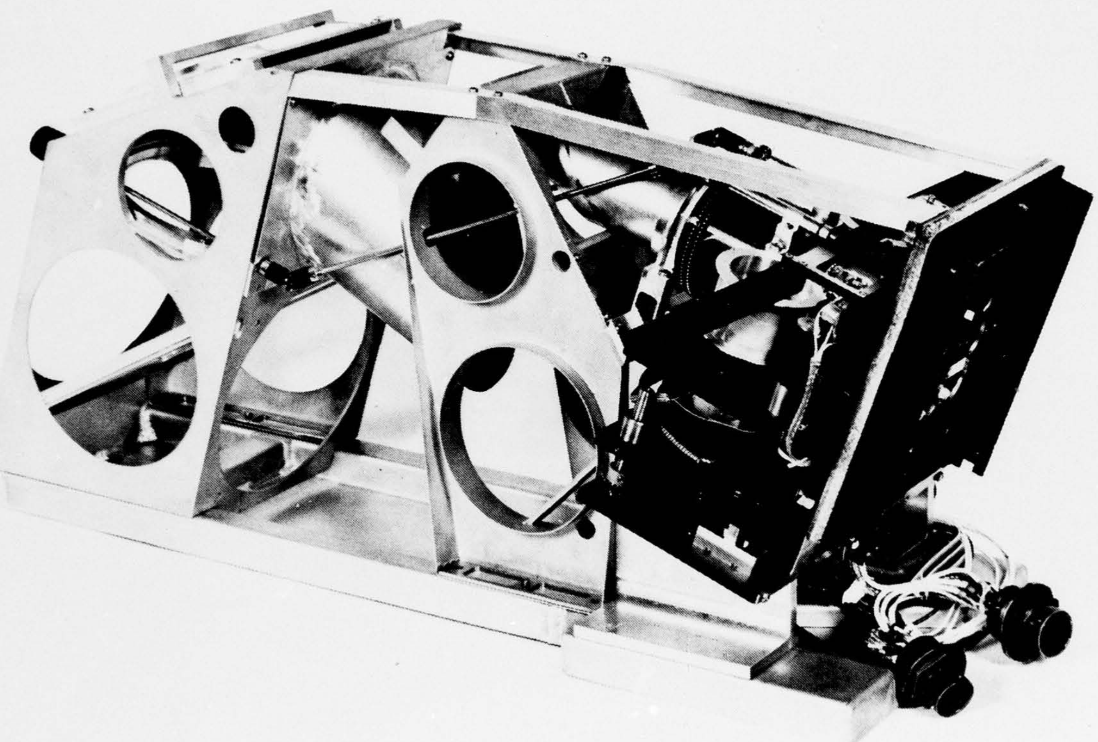


FIG. 5-2. MULTICOLOR PROJECTION SYSTEM IMPLEMENTATION

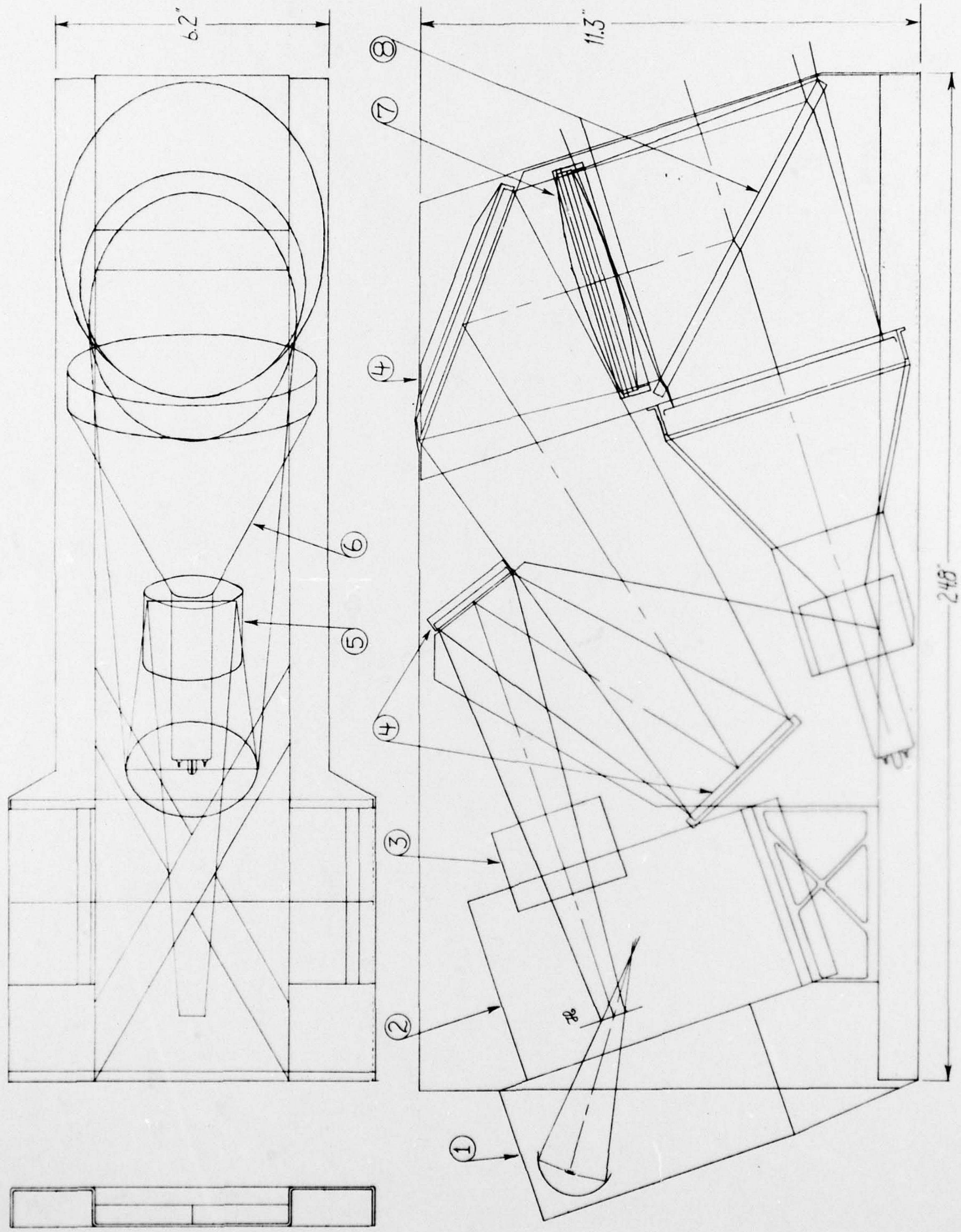


FIG. 5-3. DISPLAY HEAD OUTLINE CONFIGURATION

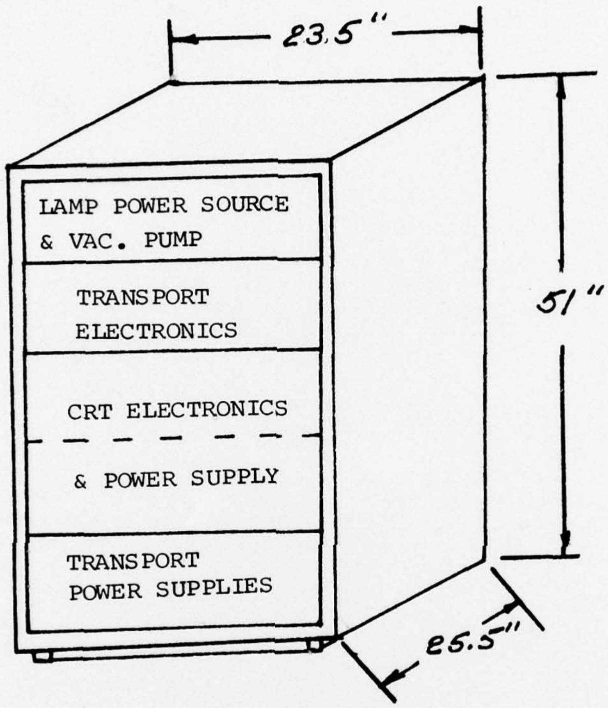


FIG. 5-4. ELECTRONICS RACK

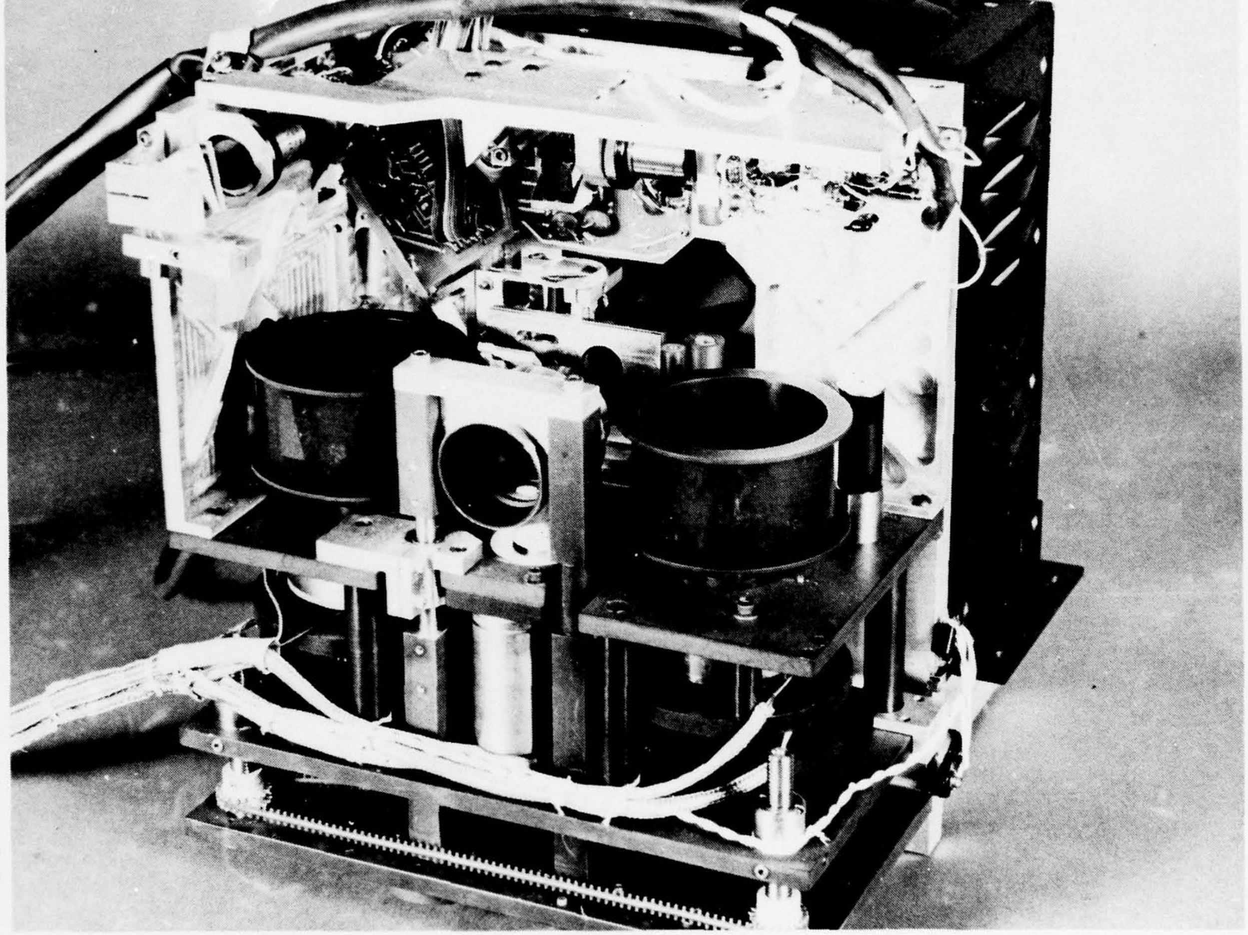


FIG. 5-5. TRANSPORT MECHANISM

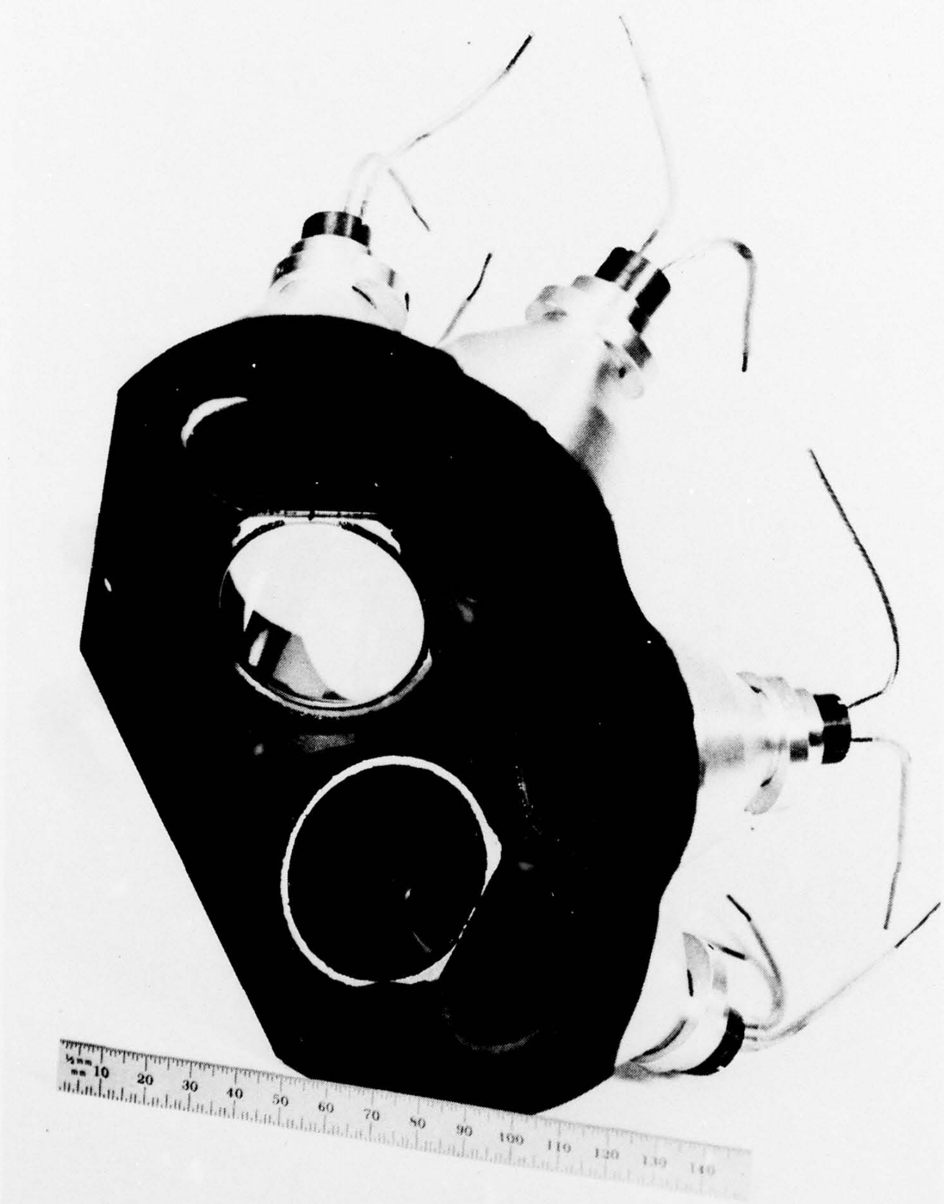


FIG. 5-6. SOURCE ASSEMBLY

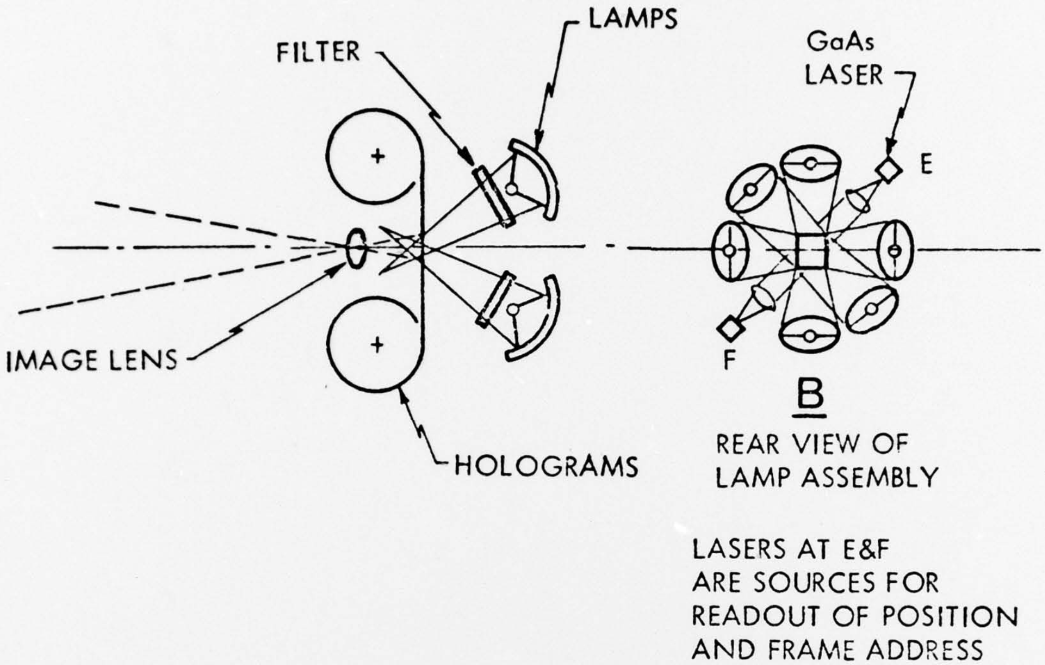


FIG. 5-7. SOURCE ASSEMBLY SCHEMATIC

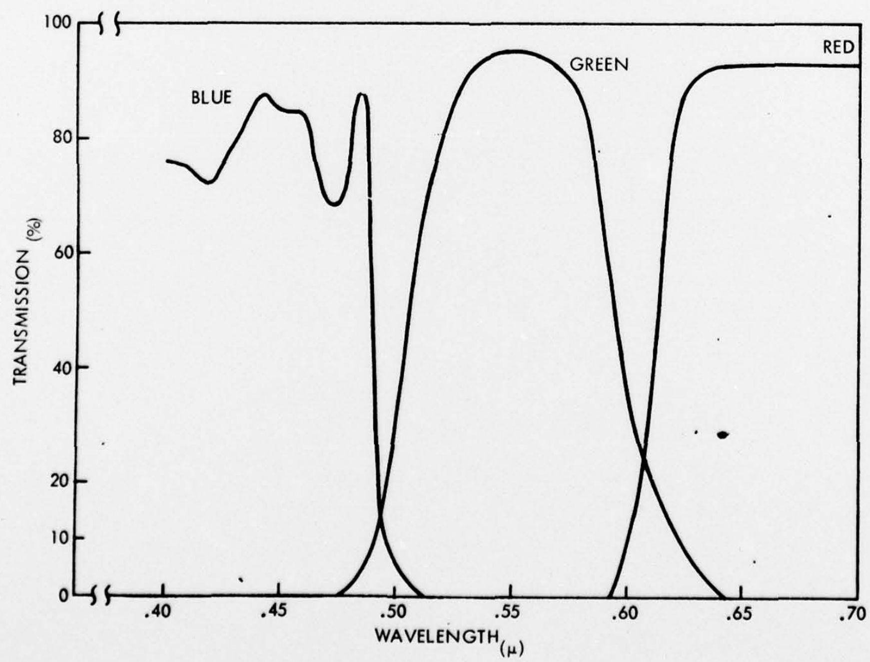


FIG. 5-8. FILTER CHARACTERISTICS

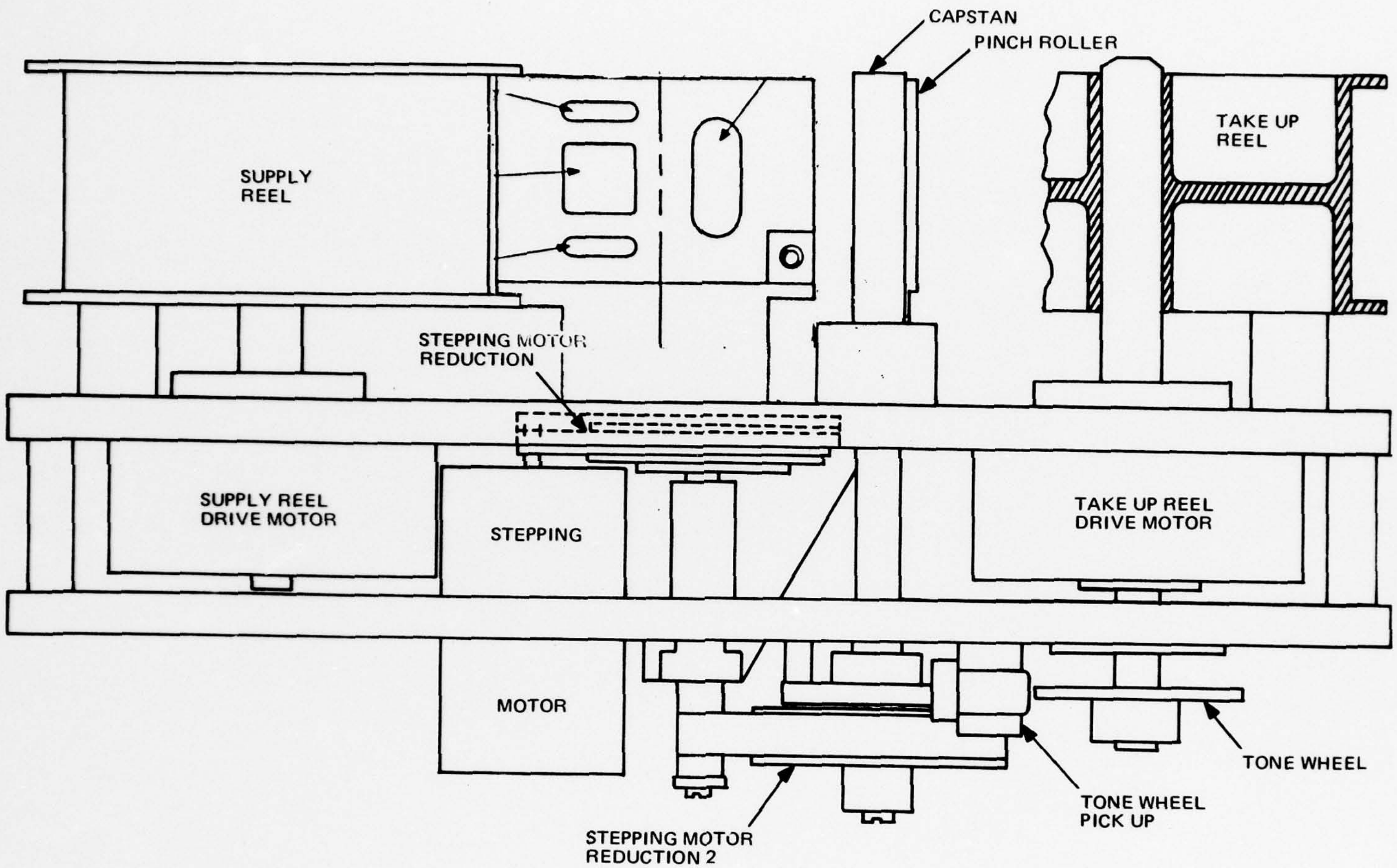


FIG. 5-9. TRANSPORT MECHANISM

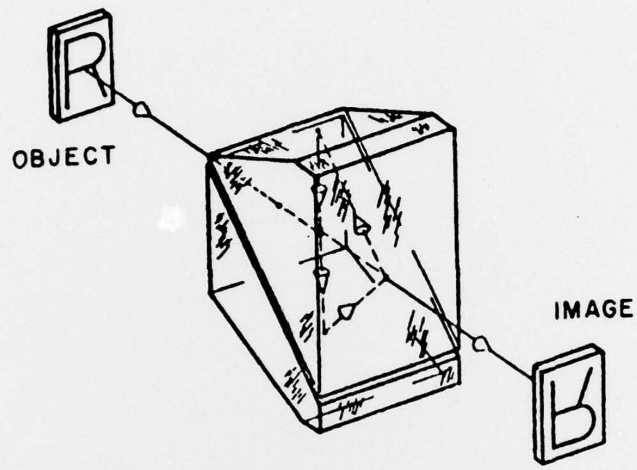


FIG. 5-10. PECHAN PRISM CONFIGURATION

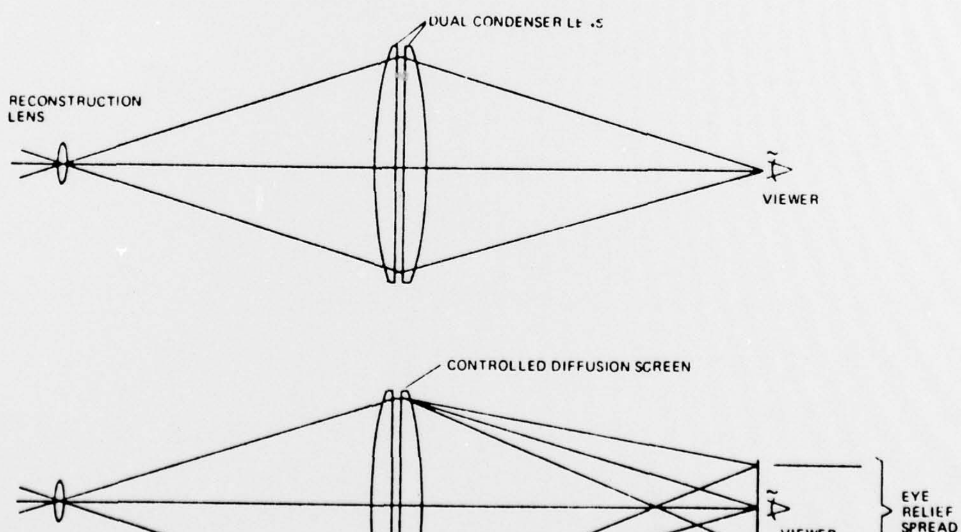
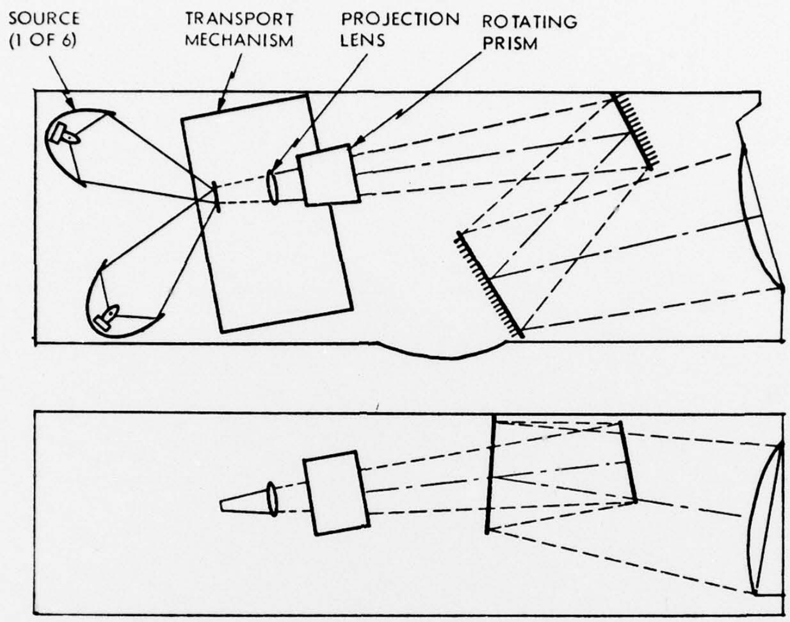
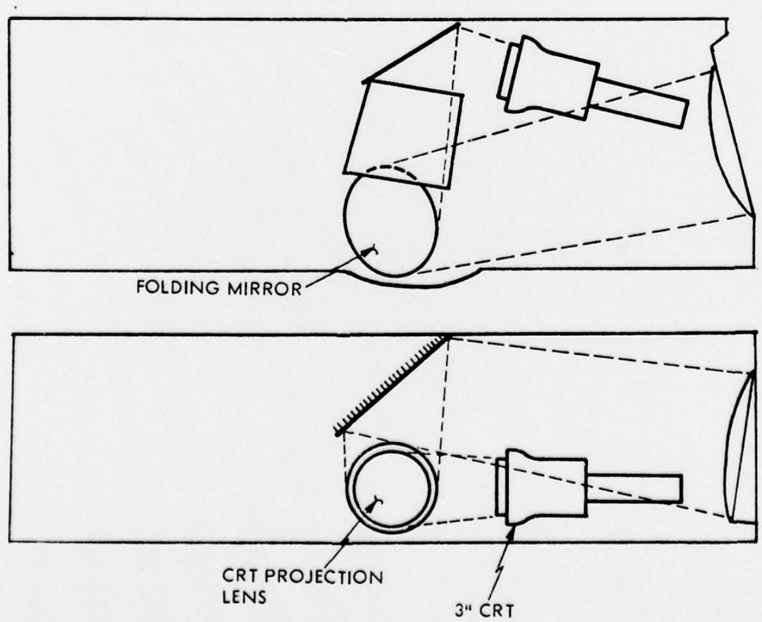


FIG. 5-11. VIEWING SCREEN CONFIGURATION



(a) HOLOGRAPHIC SUBSYSTEM



(b) ANNOTATION SUBSYSTEM

FIG. 6-1. PROJECTION OPTICS